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THE DEVELOPMENT OF SOCIAL COGNITIVE PROCESSES DURING ADOLESCENCE

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PhD

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Declaration

'I, Stephanie Sara Thompson, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.'

Abstract

This thesis presents studies investigating three aspects of social cognition: mentalising (the ability to infer the mental states of other people), empathy and emotion processing. First, the development of these social cognitive processes over the course of adolescence was investigated due to post-mortem and structural imaging research showing protracted development of several brain regions associated with social cognition during this time. Second, mentalising and emotion processing were investigated in autism spectrum disorder (ASD), a developmental disorder characterised by impaired social cognition.

The first set of studies investigated mentalising using a novel computerised task. Adults with ASD showed a significant difference in response time to mentalising compared to non-mentalising scenarios relative to control subjects matched for age and IQ. The same novel mentalising task was administered to typically-developing children, adolescents and adults. While there was evidence of general cognitive development, this was not specific to mentalising. A second mentalising study also found no change in the ability to recognise intention from eye gaze during adolescence. In the fourth study, data from a self-report questionnaire found increased empathy over the course of adolescence. The last set of studies investigated emotion processing. Using animations and facial expression tasks, no change in basic emotion processing during adolescence was found. In contrast, increased 'mixed' (simultaneous) emotion processing for social but not basic emotions during this time was found using a novel self-report questionnaire. Using the same questionnaire, adults with ASD and IQ matched controls showed comparable performance for both basic and social emotion processing.

While no change in the ability to mentalise was found during adolescence, the results of the empathy and social emotion studies suggest further social cognitive development occurs in certain domains. These findings are discussed in the context of adolescent brain development and social development during this period of life. In addition, this thesis presents consideration of findings relating the nature of mentalising and emotion processing in ASD.

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Chapter 1

INTRODUCTION

1.1 What is 'social cognition'

Social cognition refers to the way in which people think about, understand, and respond to other people. In this thesis, three interrelated aspects of social cognition were investigated: mentalising, empathy, and emotion processing. Mentalising or 'Theory of Mind (Premack & Woodruff, 1978) is the ability to understand the thoughts and intentions of other people. It has a number of important functions, including communicating intentions and developing shared goals and aims (Baron-Cohen, 1999a). Empathy describes the sharing of subjective experiences and emotions with others, and often requires mentalising. For example, when seeing someone distressed you are likely to infer that they feel upset, and their anguish may cause you to also feel upset or 'empathise' with them. In addition to mentalising, empathy often involves emotion processing, which also plays an important role in social interaction (Lobaugh et al., 2006). The recognition and understanding of one's own and others' emotional states enables communication and monitoring, evaluation, and modification of reactions (Thompson, 1994). While the ability to mentalise is often required for understanding one's own and other people's subjective experiences (empathy) and emotions, these capacities in turn provide information regarding the mental states and intentions of others (Baron-Cohen, 1995).

The neural correlates of these aspects of social cognition have recently been investigated in healthy adults using imaging techniques. Activation of regions of the frontal and temporal cortices have been found during tasks involving mentalising (Frith & Frith, 2003; 2006; Castelli et al, 2000; 2002), empathy (Farrow et al., 2001; Decety & Chaminade, 2003) and emotion processing (Kesler-West et al., 2001; Moll et al., 2002a,b). In addition, these regions show atypical activation in autism spectrum disorder (ASD; Wing, 1996) (e.g. Castelli et al., 2002; Happé et al., 1996), a disorder characterised by impaired social cognition (Frith & Frith, 2003).

In children, abilities pertaining to mentalising, empathy, and emotion processing have been well documented with age-related progression of these social cognitive capacities occurring into late childhood. However, little research has investigated change in social cognition during adolescence, despite recent imaging studies indicating continued development of regions of the frontal and temporal lobes of the brain during this time (e.g. Giedd et al., 1999; Paus et al., 1999; Sowell et al., 1999). Such protracted development of regions associated with social cognition may impact on mentalising, empathy, and emotion processing, during adolescence.

The aim of this thesis was therefore to investigate change in social cognition during adolescence, as a result of protracted development of key regions of the social brain network. Due to its developmental nature, and the atypical activation of brain regions associated with social cognition, mentalising and emotion processing in autism was also investigated. This introduction first presents studies detailing the neural correlates of mentalising, empathy, and emotion processing in adults. Next, the development of these social cognitive abilities during childhood is described, followed by literature demonstrating the nature of social cognitive impairment in ASD. The period of adolescence is then presented, with studies finding continued development of frontal and temporal brain regions associated with mentalising, empathy, and emotion processing, during this time. The possible impact of this development on social cognition in adolescence is then discussed, with the small number of studies available to date suggesting further social cognitive change occurring during this time. Finally, the aims and predictions of the present thesis are presented.

1.2 Social Cognition in adults

1.2.1 Neural correlates of mentalising in adults

Neuroimaging research has consistently indicated that activation of three regions of the 'social brain', namely the medial prefrontal cortex (mPFC), the superior temporal sulcus (STS), and the temporal poles bilaterally, are involved in inferring the mental states of other people (Gallagher & Frith, 2003). Tasks designed to engage mentalising have often involved working out the beliefs and intentions of characters in stories (e.g. Goel et al., 1995; Fletcher et al., 1995). These 'Strange Stories' (Happé, 1994) are presented on a screen inside a scanner, and a comparison is made between brain activation during stories requiring inference of a character's mental state (mentalising condition) relative to stories requiring no inference of a character's mental states (control condition). Fletcher et al. (1995) used a protocol comparing comprehension of written mentalising stories and two control conditions: 'physical stories' and unlinked sentences. Following every story there was a question, and participants read and answered each item by touching the computer screen.

An example of a mentalising story from this study is: 'A burglar who has just robbed a shop is making his getaway. As he is running home, a policeman on his beat sees him drop his glove. He doesn't know the man is a burglar, he just wants to tell him he dropped his glove. But when the policeman shouts out to the burglar, "Hey, you! Stop!", the burglar turns round, see the policeman and gives himself up. He puts his hands up and admits that he did the break-in at the local shop'. This story would be followed by the question: 'Why did the burglar do this?'. The physical stories described events similar to the mentalising condition, but did not involve inference of other people's mental states. For example: 'A burglar is about to break into a jewellers' shop. He skilfully picks the lock on the shop door. Carefully he crawls tinder the electronic detector beam. If he breaks this beam it will set off the alarm. Quietly he opens the door of the store-room and sees the gems glittering. As he reaches out, however, he steps on something soft. He hears a screech and something small and furry runs out past him, towards the shop door. Immediately the alarm sounds'. This story would be followed by the question: 'Why did the alarm go off?'. Therefore, while the content of this story was similar to that in the mentalising condition, this condition involved making a causal rather than a *mental state* attribution. A second control condition was also included (unlinked sentences) whereby neither causal nor mental state attributions were required. An example of an item from the unlinked sentences from this study condition is: 'The four brothers stood aside to make room for their sister, Stella. Jill repeated the experiment, several times. The name of the airport had changed. Louise uncorked a little bottle of oil. The two children had to abandon their daily walk. She took a suite in a grand hotel. It was already twenty years since the operation'. This story would be followed by the question 'Did the children take their walk?'.

Significantly greater activation in the left mPFC, anterior cingulate and right posterior cingulate cortices, and inferior parietal lobe, was found during the mentalising relative to physical stories. Mentalising verses unlinked sentences showed significantly greater activation in the temporal poles bilaterally, the left superior temporal gyrus, the posterior cingulate and left mPFC (Fletcher et al., 1995). This demonstrates the involvement of the mPFC in mentalising in adults.

Activation of the mPFC has also been found when inferring mental states of cartoon characters. In addition to the stories used in Fletcher et al.'s (1995) study, Gallagher et al. (2000) presented six adults with three corresponding types of caption-less cartoons (mentalising, non-mentalising, and jumbled). Examples are presented in Figure 1.1.

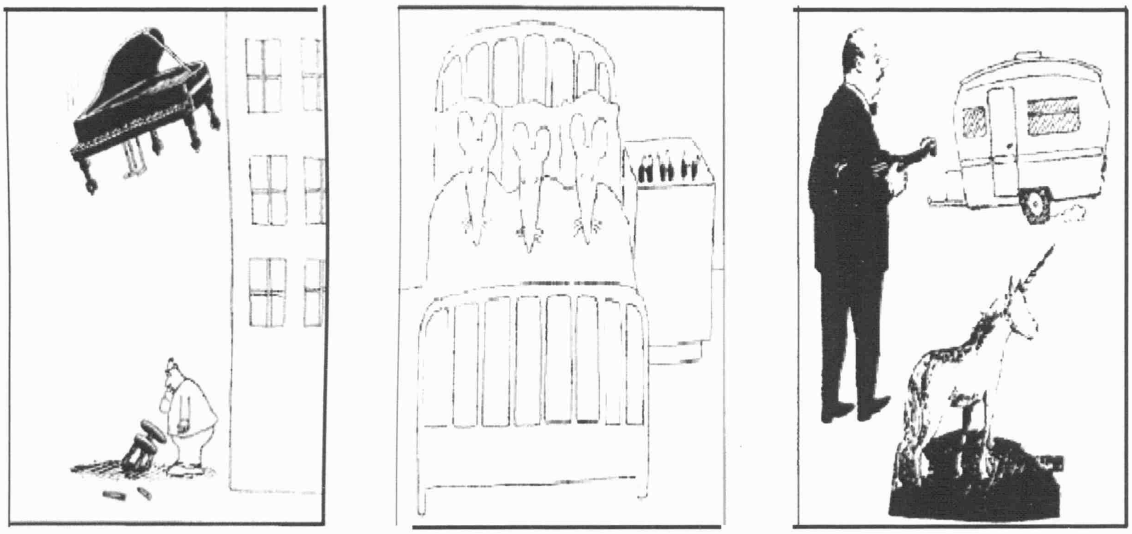

Figure 1.1: Example of a mentalising cartoon, a non-mentalising cartoon, and a jumbled cartoon (Gallagher et al, 2000). The mentalising cartoon is the only condition requiring mental state inferences to understand the cartoon's meaning. This example requires inferring that while the man is looking at the piano stool, he does not realise that the piano is falling down above him.

As in the Fletcher et al. (1995) study, participants were asked to read silently each item and answer the corresponding question in the scanner. For the cartoons, participants were presented with each image and asked to silently consider its meaning. For both mentalising stories and cartoons, there was increased activation of the mPFC, indicating the specificity of this region to the processing of mental states regardless of modality (Gallagher et al, 2000).

The specificity of mPFC to mentalising is further evidenced by research showing mPFC activation during attribution of mental states to inanimate objects, such as geometric shapes that appear to move in 'lifelike' patterns (Castelli et al., 2000). See Figure 1.2.

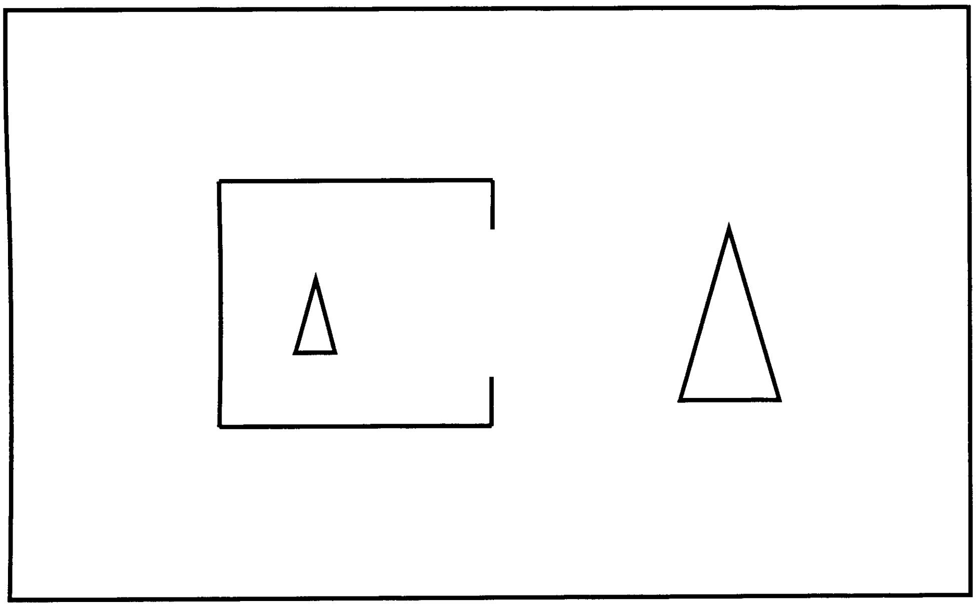

Figure 1.2: Example of an item from the animations task, adapted from Castelli et al. (2000). In the task, the triangles moved in one of three ways: mentalising, goal-directed, or random. The mentalising condition was the only condition in which the triangles appeared to interact intentionally with each other (e.g. tricking, coaxing), therefore eliciting mental state attributions.

This paradigm was originally developed by Heider and Simmel in 1944 in which two moving triangles appear to be moving in human-like ways (e.g. chasing each other). These types of animation have consistently been found to elicit spontaneous mental state attributions in adults (Heider & Simmel, 1944; Castelli et al., 2000; Blakemore et al., 2003; Schultz et al., 2004; Boraston et al., 2006). Castelli et al. (2000) presented 10 adult participants with a series of animations in three conditions: mentalising, goal-directed, and random, movement. Mentalising was the only condition that required inference of mental states and intentions (e.g. coaxing or tricking). Goal-directed (e.g. chasing) and random movement conditions did not involve mental state attributions. Greater activation in mPFC, inferior temporal gyrus, and STS at the temporo-parietal junction occurred during mentalising relative to control conditions was found (Castelli et al., 2000).

In addition, studies have found activation of the mPFC when participants believe that they are playing against a human (therefore attributing mental states to an unseen person) compared to a machine (Gallagher et al., 2002; Rilling et al., 2004). For example, Gallagher et al. (2002) presented participants with the game 'paper-rock-scissors' requiring the subject to make a series of competitive hand movements to try to win by guessing the intentions of the opponent. There were two conditions: human opponent and computer opponent. However, identical sets of sequences were made by the 'opponent' (a computer program) regardless of condition. The only difference between conditions was the *belief* that another person was present in the human opponent condition, and that their performance may be predicted by making inferences about their mental state. Consistent with this, activation of the mPFC was seen only when participants believed they were playing against a human competitor. This indicates that the mere belief that another person is present is sufficient to engage mentalising and so activate the mPFC (Gallagher et al., 2002).

Patient studies have also emphasised the importance of the mPFC in mentalising (e.g. Stone et al., 1998; Stuss et al., 2001). For example, Stuss et al. (2001) reported impaired ability to detect intentional deception in individuals with damage to the ventral mPFC relative to control participants. During this task, objects were hidden in one of two containers, out of sight of the participant but in front of an 'assistant' who would consistently direct them toward the incorrect container. The failure by the patients in understanding that the assistant was trying to deceive them may suggest that damage to the ventral mPFC results in impoverished understanding of other people's intentions. However, Bird et al. (2004) report no significant impairment of mentalising ability on tests including the strange story and animations paradigms already described, in a patient who had suffered a rare form of stroke that had caused extensive damage to the mPFC. The discrepancy between this result and other studies may have arisen from the use of patients who had suffered head trauma, as in Stuss et al.'s (2001) study, whereby the extent of brain damage is often difficult to ascertain due to axonal shearing and other effects (e.g. Pang, 1989; cited in Bird et al., 2004). In addition, Bird et al. (2004) note that head trauma patients often have profound cognitive impairments while structural scans may appear normal (e.g. Richardson, 2000). Therefore, while some preliminary evidence suggests damage to the mPFC may result in impoverished mentalising as in Stuss et al.'s (2001) study, additional research may also be required to ascertain the impact of mPFC damage on the ability to mentalise (Bird et al., 2004).

The ability to infer the mental states of other people provides information about their subjective experiences, which is an important aspect of empathy. Similar to mentalising, research investigating the neural correlates of empathy in adults has found activation of the frontal cortex including the PFC, and is the topic of the next section.

1.2.2 Neural correlates of empathy in adults

There is a 'social brain' theory regarding the neural basis of empathy in which the involvement of three main brain regions, namely the medial frontal and orbitofrontal cortices, the amygdala, and STS, are postulated to be of importance for experiencing empathy toward others (Brothers, 1990). Imaging studies with adults have found increased activation of brain regions including the PFC during tasks of empathy (e.g. Farrow et al., 2001; Decety & Chaminade, 2003). For example, Decety and Chaminade (2003) presented participants with a series of video clips in which actors described either neutral or sad stories. The sad stories were designed to induce feelings of empathy, and increased activation of the anterior superior frontal gyrus, inferior frontal gyrus, temporal pole, and amygdala, was found for the sad relative to the neutral video clips (Decety & Chaminade, 2003). Farrow et al. (2001) presented 10 adults with detailed scenarios in three conditions: social reasoning (e.g. 'traffic causing delays, it is not rush hour'), empathy (e.g. 'boss acting withdrawn, you sense something is wrong') and forgiveness (e.g. 'young man is visited by police, he lives on your street'). Two possible explanations for each situation were given following the presentation of scenarios, and participants were required to select the most likely explanation. Relative to the social reasoning condition, both empathic and forgivability judgements showed significant activation of the left superior frontal gyrus, orbitofrontal gyrus and precuneus. However, there was additional activation of the left anterior middle temporal and left inferior frontal gyri in the empathy relative to forgivability condition, indicating a specific role for these regions in empathic responses (Farrow et al., 2001).

Empathic processes are impaired among patients with PFC damage (Eslinger, 1998). For example, patients with ventromedial PFC lesions demonstrated significantly lower empathy scores compared to patients with posterior lesions and healthy controls (Shamay-Tsoory et al., 2003). In this study, empathy was significantly correlated with the ability to mentalise, demonstrating the important role played by the PFC in mediating empathic responses in adults.

Emotion processing also involves understanding of own and other people's affective experiences, and like empathy and mentalising this ability in adults has been the topic of much imaging research. Studies that have investigated the neural correlates of emotion processing in adults are presented in the next section.

1.2.3 Neural correlates of emotion processing in adults

Distinct regions of the frontal cortex have been found to support personal emotional responses and inference of the emotional states of other people. For example, Ochsner et al. (2004) presented 13 adults with photos of varying emotional valence. Participants were asked either to give their own emotional response to the stimuli, to imagine and articulate the emotional response of a character depicted in the stimuli, or to judge whether the photo was taken indoors or outdoors. The results indicated significant activation of the mPFC, STS and posterior cingulate in both the self (own emotional response) and other (infer another person's emotional response) emotion conditions compared with baseline (indoors/outdoors). These data suggest that the social brain network activated during mental state attribution supports the attribution of self and other emotion (Ochsner et al., 2004).

Similarly, Lane et al. (1997) presented 10 adult male participants with six different types of emotional picture sets which varied in the amount of emotional (pleasant to unpleasant) stimuli presented in comparison to neutral stimuli. Participants were either asked to make an internal judgment of how the picture made them feel, or make an external judgment of whether the picture was taken indoors or outdoors. Increased activity in the rostral ACC was found when participants reflected upon their subjective emotional response to the pictures compared to when they were asked to make the external judgement, consistent with the involvement of associated mPFC regions of the brain in processing emotional stimuli (Lane et al, 1997).

Emotions may be divided into two different types: basic and social. Basic emotions such as fear and anger are universally recognised (Ekman, 1972; 1999) and have high evolutionary value. For example, a snarling dog is likely to elicit feelings of fear and result in behavioural avoidance to minimise risk of attack. In contrast, social emotions such as embarrassment and guilt involve mentalising, and often depend on social and cultural norms. For example, if you are unkind to a friend you may feel guilt due to inferring that other people would disapprove of your actions.

Ekman et al. (1982) proposed that there are six basic emotions: happy, sad, angry, fear, disgust, and surprise. These emotions are reliably identified from facial stimuli

(Kirouac & Dore, 1985) and recognised and expressed across cultures (Ekman, 1972; 1999). Activation of the amygdala has been consistently found during tasks involving basic emotion processing (Berthoz et al., 2002). A number of studies using face perception paradigms, involving the presentation of a photograph of an actor's face expressing different emotions (e.g. Breiter et al., 1996; Morris et al., 1996; 1998; Phillips et al., 1998b) have found that, relative to neutral faces, fearful faces elicit activation of the left anterior amygdala. Blair et al. (1999) found increased activation of the amygdala and temporal (inferior and middle) gyri in response to photographs of people's faces showing sad relative to neutral expressions. However, research also suggests a role for the frontal cortex in processing basic emotion. Blair et al. (1999) found increased activity in the orbitofrontal cortex and anterior cingulate cortex in angry relative to neutral expressions of emotion. Kesler-West et al. (2001) found increased activation of medial frontal regions during conscious processing of basic (happy, sad, anger, fear) emotions in participants aged 18-45 years, consistent with a similar study by Sprengelmeyer et al. (1998).

Consistent with social emotions having an inherent mentalising component, greater activation of the PFC and STS has been found during the processing of social relative to basic emotions (Moll et al., 2002a,b). Moll et al. (2002b) compared responses to scenes involving either basic emotions (fear and disgust) or socio-moral emotions (compassion and indignation) where an evaluation of 'right' or 'wrong' is based on social norms. While both basic and socio-moral emotions activated the thalamus, amygdala, and upper midbrain, the socio-moral emotions additionally activated the medial orbitofrontal, fronto polar, and medial frontal cortices and the posterior STS. In addition, Moll et al. (2002a) found preferential activation of the medial orbitofrontal cortex and posterior STS when participants made judgements about statements evocative of social emotions (indignation and compassion) compared to statements evocative of basic emotions (fear and disgust). This emphasises the involvement of orbital and medial regions of the PFC and the STS region in the processing of socio-moral emotion (Moll et al., 2002a; b).

Adult lesion studies also highlight the importance of the frontal cortex in the generation and control of social emotions. Patients with orbitofrontal damage demonstrate deficits in both feeling and understanding embarrassment compared to controls (e.g. Beer et al., 2003). Beer et al. (2003) investigated the responses of five orbitofrontal patients and five healthy controls on a self disclosure task and a teasing task. Compared with control subjects, the patients were significantly worse at recognising social, but not basic, emotions in others. Patients also became unnecessarily embarrassed in situations that were not appropriate, emphasising atypical socio-emotional responses and deficiencies in behavioural regulation associated with orbitofrontal damage (Beer et al., 2003).

1.2.4 Summary: Social cognition in adults

Imaging research with adults has indicated activation of a brain network involving frontal and temporal regions such as the PFC and STS during tasks involving mentalising, emotion, and empathy. These abilities have been found to develop over the course of childhood, and are presented in the next section.

1.3 Development of Social Cognition during childhood

From birth, human infants demonstrate a preference for faces over other objects. This has been inferred from research finding that moving face-like patterns elicit more following behaviour (Morton & Johnson, 1991) and eye gaze (Kleiner, 1987; Umilta et al., 1996) in newborns. The face is a rich source of information about the internal states of other people, and the utilisation of this important social resource by newborn infants suggests that the beginning of a complex social cognitive system may be present from a very young age. The capacity for complex social cognition develops further over the course of childhood.

1.3.1 Mentalising in childhood

Understanding the goals and intentions of other people plays an important role in understanding the social world, as it links the observation of other people's actions to their feelings and thoughts (Rotenberg, 1980). During the first year of life, infants develop sensitivity to eye gaze of others (Barresi & Moore, 1996), engage in joint attention (Butterworth & Jarrett, 1991), and begin to use information about the emotional states of other people to regulate behaviour in novel or uncertain situations (Feinman, 1982).

By the age of three and a half, children begin making references to the mental states of other people, using words such as 'think' and 'know' in their spontaneous daily language. This may indicate an ability to separate the thoughts of others (beliefs) and the reality of the world (Shatz et al., 1983). Around the age of four years, children are considered to have an explicit understanding of what other people are thinking, and to be able to use this knowledge to predict their behaviour (Perner & Wimmer, 1985). For example, compared with three year olds, children aged four succeed on 'false belief' tasks (Wimmer & Perner, 1983). This involves the presentation of a scenario with two characters, for example, 'Sally' and 'Anne'. Sally has a marble, which she puts in a cupboard before leaving the room. During her absence, Anne moves the marble from the cupboard and puts it in a box. Sally then re-enters the room, and participants are asked 'where will Sally look for the marble?' Understanding that Sally will not know the new location of the marble because she was not in the room when it was moved relies on the ability to distinguish between what people believe (in the cupboard) and what is true (in the box).

Three to four years might therefore reflect a critical period for mentalising (Smith et al., 1998), and four years has been widely considered to be the landmark age for this ability (Premack & Woodruff, 1986). Perhaps due to this, few studies have investigated mentalising past this age. Anecdotal evidence however has suggested that mentalising continues to change past age four (e.g. Rotenberg, 1980; Slaughter et al., 2002; Wellman and Liu, 2004; Reches & Pereira, 2007). Reches and Pereira (2007) found improved performance on various mentalising tasks including false belief, between the ages of three to six. Sodian and Schneider (1990) presented children aged four to six with a task investigating the ability to intentionally deceive others by hiding objects using different semantic labels. While none of the four year olds and only half of the five year olds were able to hide objects from other people, almost all of the six year olds were able to do so. These data indicate developmental differences in the ability to intentionally deceive others, a skill requiring mentalising (knowing what someone does and doesn't know), up to age six years.

Further change in mentalising has been found to occur during late childhood. Baron-Cohen et al. (1999b) presented children aged from seven to 11 years with stories describing conversations between two or three characters in which one character says something socially inappropriate (a 'faux pas'). The ability to detect and explain these faux pas was found to improve between seven and 11 years. In addition, Baron-Cohen et al. (2001b) found that the ability to infer intention from eye gaze improves between the ages of six to 12 years.

Research therefore indicates that change in the ability to mentalise occurs into late childhood. While less well researched, similar age-related developments have been found in empathy and emotion processing during childhood.

1.3.2 Empathy in childhood

As early as 14 to 20 months of age, infants demonstrate empathic responses when viewing simulations of other people in distress (Zahn-Waxler et al., 1992) and such responding shows continued development over the course of childhood. Between five and 13 years, children become more able to focus on and respond emotionally to the subjective experience of another person (Strayer, 1993). Strayer (1993) presented 138 children aged five, seven to eight, and 13 years with two sets of vignettes depicting emotional scenes. Participants watched each vignette and then described the main emotion that each vignette made them feel (e.g. sadness, happiness etc). Responses were scored on the basis of whether their feelings matched those of the main character in the vignette (i.e. if the participants felt empathetic concern). The results indicated linear increases in the accuracy of response, implying a progressive improvement in empathic abilities up to age 13.

1.3.3 Emotion processing in childhood

Displays of emotion in response to pleasant and unpleasant stimuli are found during infancy (Ganchrow et al., 1983) and facial expressions associated with basic emotions such as anger, happiness, and fear, are demonstrated within the first nine months of life (Izard et al., 1980). The use of terms relating to basic emotions such as 'surprised' and 'scared' increases between 18 and 24 months, when children use these emotional words with increasing frequency in everyday language to refer to emotional experiences (Bretherton et al, 1986). Between the ages of three and four, children increasingly use display rules (Gnepp & Hess, 1986), which are culturally defined and influence behavioural conformity toward social norms. For example, children as young as three years hide disappointment when given an unappealing present (Cole, 1986).

The ability to recognise facial expressions of emotion also develops over childhood. Adams et al. (1993) found significant age-related improvement in the ability to identify the emotions of other people between the ages of three to five years. Pons et al. (2003) asked 80 children aged from four to 11 years to select one out of four possible emotions (happy, sad, neutral, scared) they felt matched the response of a person in a drawing. Accuracy was found to improve with age and this result is consistent with other studies investigating the development of emotion recognition up to age 11 (e.g. Workman et al., 2006). This is also around the age that children develop an understanding of 'mixed emotion', i.e. the ability to feel more than one emotion at the same time (see Harris, 1989). The development of mixed emotion around age 10 has been suggested to be the result of understanding that the same situation can make you feel more than one emotion, as well as knowledge that past events may influence current feelings (Harris, 1989).

Change in abilities pertaining to emotion processing may also be found during adolescence. Ekman and Friesen (1978) developed a Facial Action Coding System (FACS) in which 33 facial movements (or 'action units') were recorded as being necessary and representative of the six basic emotional expressions (happy, sad, angry, fear, disgust, surprise; Ekman et al., 1982). For example, raising the corners of the mouth to smile would be indicative of a happy emotional expression. Participants were asked to reproduce the emotional expressions shown in a series of faces, and scored on the basis of the number of correct action units produced. When employed with children aged five to eight, and adolescents aged 13-14, Ekman et al. (1980) found higher scores in the older relative to the younger group, indicating an improvement in the ability to produce deliberate facial expressions of emotion up to 14 years.

1.3.4 Summary: Social cognition during childhood

The first section of this introduction demonstrated the association between a distinct brain network including the PFC in mentalising, empathy, and emotion processing in adults. In this section, research has indicated progressive improvements in these three aspects of social cognition over the course of childhood.

The next section presents literature describing mentalising, then emotion processing, in ASD. ASD is a disorder characterised by impaired social cognition (Frith & Frith, 2003). Difficulties with mentalising and emotion processing have been demonstrated by both children and adults with ASD. In addition, research has indicated atypical activation of frontal and temporal regions in adults with ASD during tasks of social cognition.

1.4 Mentalising and emotion processing in autism

Autism is a developmental disorder characterised by impaired social cognition. It has a prevalence rate of about 1 in 100 in the UK, and males are four times more likely to have ASD than females (Baird et al., 2006). A diagnosis of autism is made when there are persistent difficulties in social interaction (e.g. failure to develop age-appropriate peer relationships), communication (e.g. delay in or lack of spoken language development), and stereotyped patterns of behaviour (e.g. repetitive motor mannerisms) prior to age three years (DSM-IV, 1994). The severity of symptoms in autism can range from highly impaired, combined with an IQ lower than 70, to relatively high functioning, combined with average to high IQ, and this continuum is referred to as ASD (Wing, 1996). Asperger syndrome (AS) forms part of this continuum, and is often thought of as 'high functioning' autism (HFA), as individuals with AS have relatively high intelligence and functioning in comparison with classically autistic individuals. Diagnosis of AS requires the qualitative impairment in social interaction and preoccupation with stereotyped activities as in classic autism but without a clinically significant delay in language, cognitive development, or adaptive behaviour. In addition, the term pervasive developmental disorder not otherwise specified (PDD-

NOS) refers to individuals who have difficulties in more than one area but do not fulfil the diagnostic criteria for autism or AS (Buitelaar et al., 1999).

Individuals with ASD demonstrate deficits in social orienting (e.g. Dawson et al, 1998; 2004), emotional responsivity (e.g. Sigman et al., 1992), joint attention (e.g. Mundy & Sigman, 1989) and facial recognition (e.g. Klin et al, 1999). These impairments are often present from early childhood and may remain throughout the course of development. Impaired mentalising in ASD will now be discussed.

1.4.1 Mentalising in autism

While typically developing (TD) children engage in pretend play around age two years (Fein, 1981) and succeed at mentalising tasks around age four (Wimmer & Perner, 1983; Perner & Wimmer, 1985) these social communicative advances are delayed or absent in children with ASD (Baron-Cohen et al., 1985). Baron-Cohen et al. (1985) found that, despite having higher mental ages than children with Down's syndrome and TD controls, in a sample of 20 children with ASD, 16 failed to successfully infer the mental state of a character in a false belief task. Similar findings have been found using a Strange Story paradigm (see Fletcher et al., 1995 in section 1.2.1 above) with adults with ASD, whereby impaired performance in understanding the mental states of characters in short stories was demonstrated in ASD compared with controls (Happé, 1994).

Further evidence for a specific difficulty in mentalising comes from studies employing 'false photographs' (e.g. Leekham & Perner, 1991; Binnie & Williams, 2002) or drawings (e.g. Charman & Baron-Cohen, 1992). In these tasks, past reality is represented in a similar way as mistaken belief yet children with ASD are more able to understand the difference between their content and reality, compared with understanding the content of other people's minds, as in the false belief paradigm.

In addition, strategies such as the use of cues or prompts toward mentalising have been found to increase accuracy on mentalising tasks. For example, Parsons and Mitchell (1999) found that children with ASD who had a verbal mental age of seven years and six months successfully interpret what characters in pictures were thinking about when the characters had 'thought bubbles' drawn above their heads (i.e. had a false belief). This suggests that the ability to understand other people's mental states may exist but is not automatically engaged in ASD.

This could be consistent with studies that have not found impaired mentalising in ASD. For example, Russell and Hill (2001) found intact reporting of other people's intentions by children with autism relative to children with moderate learning disabilities and TD children, matched for verbal age. In addition, between 15 and 55% of individuals with autism are able to pass 'first order' (infer the mental states of another person) false belief tests (Happé & Frith, 1996). Tager-Flusberg and Sullivan (1994) and Sullivan et al. (1994) have suggested that failure by individuals with ASD on such tasks may be due to the advanced information-processing abilities required, rather than an inability to infer the mental states of others. For example, simplifying task material by decreasing the length, complexity, and format of stories, resulted in almost half of participants with ASD providing adequate mental state descriptions (Sullivan et al., 1994). Using the same task stimuli, Tager-Flusberg and Sullivan (1994) found no differences between individuals with ASD and a control group of matched mentally retarded (MR) participants in mentalising ability.

These results contradict research finding specific mentalising deficits in ASD relative to matched MR controls (e.g. Baron-Cohen at el., 1985; Ozonoff et al., 1991), and the distinction between individuals with ASD who pass such tasks and those who do not is unclear. However, individuals with ASD who succeed at mentalising tend to be older and more verbal than those who fail (Happé et al, 1994) and an association between performance on mentalising tasks and language has been found (Tager-Flusberg et al., 2001). Other possibilities include the suggestion that individuals with ASD who are successful at mentalising tasks use cognitive strategies other than mentalising, or are a subset of the ASD population with distinct aetiology (Happé & Frith, 1996). There may also be a differentiation between the ability to engage in theory of mind with other people in the real world, and performance on tasks of theory of mind in laboratories. Thus, while the social abilities of people with high functioning autism are often impaired, empirical research on their mentalising abilities has been inconsistent.

Imaging research has indicated that the PFC shows atypical activation during tasks of mentalising in ASD. Happé et al. (1996) found an absence of activation of the left PFC during the analysis of mentalising stories in adults with ASD compared with controls. Castelli et al. (2002) presented adults with ASD and controls with an animations task (described in section 1.2.1). While viewing the mentalising animations compared to the random animations, less activation of the mPFC, STS at the temporo-parietal junction, and the temporal poles, was found in ASD relative to controls. Given the involvement of these regions and mentalising in healthy adults (Frith & Frith, 2003; Castelli et al, 2002), decreased activation of these regions in ASD may reflect weaker activation of the social brain network during situations requiring mentalising (Castelli et al., 2002).

Therefore, while evidence suggests hypoactivity in frontal regions such as the PFC during social cognitive tasks in ASD, there is mixed research as to the nature of mentalising impairment in ASD. Research pertaining to the processing of basic emotions in ASD has been similarly inconsistent, and is the topic of the next section.

1.4.2 Emotion processing in autism

Consistent with impaired mentalising in ASD (e.g. Baron-Cohen et al., 1985), studies have found impaired processing of social emotions in ASD (e.g. Capps et al., 1992; Losh & Capps, 2006). Capps et al. (1992) and Losh and Capps (2006) asked children with ASD aged 12 to describe a time when they had experienced feeling different emotions (e.g. when they had felt happy, sad, proud, guilty, etc.). Their results indicated difficulty in talking about socially-derived emotions such as embarrassment and pride, requiring more time, prompts, and producing more 'scripted' responses, relative to control children (Capps et al., 1992). Research investigating Alexithymia, a dysregulation of emotion involving difficulties in identifying and regulating feelings (Sifneos, 1973), has found significantly higher scores on self-report measures of this condition in individuals with ASD relative to relatives and controls (Hill et al., 2004). Losh and Capps (2006) suggested that individuals with ASD have difficulty encoding emotional events to a sufficient degree so that they have an impoverished knowledge base upon which to judge the causes and effects of emotional encounters. This may cause difficulty in understanding such events, particularly for situations involving social emotions such as embarrassment and guilt, due to their social nature.

In contrast, there is mixed evidence as to the existence of impaired basic emotion processing in ASD. Some studies have found no impairment in accuracy on tasks of basic emotion in ASD relative to controls (e.g. Losh & Capps, 2006; Ozonoff et al., 1990; Piggot et al., 2004). Others have found impaired descriptions of events involving basic emotions (e.g. Jaedicke et al., 1994; Rieffe et al., 2007), and of fear (e.g. Howard et al., 2000; Ashwin et al., 2007) and sadness (Boraston et al., 2006) recognition, in ASD. For example, Rieffe et al. (2007) found impoverished description of basic emotions, as well as impaired mixed (simultaneous) emotional responses to stories involving basic emotions, in children with ASD relative to TD controls. Boraston et al. (2006) developed a version of Abell et al.'s (2000) animations task (see section 1.2.1). Here, a triangular shape was portrayed as moving around a screen in a 'life like' manner, to elicit attributions of emotion. Participants were asked to judge how emotional one of the triangles appeared to be (e.g. 'How happy do you think the triangle was?') by rating the intensity of emotion for each animation on a scale of 0 (not at all) to 5 (extremely). Participants were also tested on their ability to identify the correct emotional expression on photographs of faces from a subset of the Ekman faces test (Ekman & Friesen, 1976). Adults with ASD were impaired compared with controls on judging sadness on both tasks. In addition, despite comparable levels of accuracy, subtle differences in response time to tasks involving basic emotion have been found in ASD (e.g. Piggot et al, 2004).

1.4.3 Summary: Mentalising and emotion processing in autism

There is mixed evidence as to the nature and existence of impaired mentalising and emotion processing in ASD, indicating that additional research is required to further investigate these social cognitive abilities. However, neuroimaging research has indicated that the regions typically associated with these social cognitive abilities in healthy adults, in particular the mPFC, show abnormal (decreased) activation in adults with ASD. In combination with the normative adult literature, this emphasises the importance the mPFC in social cognition. Recent imaging research has found continued development of brain regions including the mPFC into adolescence. This protracted development may impact on social cognition during this time. However, despite the wealth of research investigating the development of mentalising, empathy, and emotion processing in childhood, social cognitive change during adolescence this has not yet been widely researched. Maturational events occurring during puberty and adolescence, and the possible implications this may have on social cognition, are now discussed.

1.5 Puberty and adolescence

Puberty refers to the process of physical changes by which a child develops into an adult, and is initiated by episodic nocturnal bursts of follicle-stimulating hormone (FSH) and luteinising hormone (LH) in both males and females (Grumbach & Styne, 1998). These hormones stimulate growth and sexual development, and the period between puberty onset and completion is often referred to as 'adolescence'. Adolescence incorporates the psychological and social adaptation necessary to develop from a child to an adult.

Despite the vast hormonal, social, and psychological changes occurring during adolescence, the development of brain and cognitive functions during this time has only recently been investigated. These investigations (e.g. Giedd et al., 1999; Paus et al., 1999; Sowell et al., 1999; 2003; Gogtay et al., 2004) have found changes to the structure of the brain including regions of the frontal and temporal cortices, associated with social cognition in adults (see section 1.1.2), during adolescence. These changes have been attributed to maturational events found in adolescent human brains post-mortem (Yakovlev & Lecours, 1967; Huttenlocher, 1979). These will now be described, followed by data from structural imaging studies and consideration of the impact such protracted cortical development may have on the functional connectivity of the brain during adolescence.

1.5.1 Brain development in adolescence: cellular studies

While maturational events in regions such as the primary and sensory cortices occur during childhood, associative cortical regions such as the PFC continue to develop into adolescence (Huttenlocher, 1979; Yakovlev & Lecours, 1967). There are two cellular events associated with this development: myelination and synaptic reorganisation.

1.5.1.1 Myelination

During development, a fatty substance called 'myelin' is formed around the axons of neurons from supporting glial cells in the brain. These myelin sheaths act as electrical insulators and speed up transmission (up to 100 fold) of electrical impulses between neurons. While there is robust myelination of sensory and motor cortices during the first decade of life, axons in the frontal cortex also show increased amounts of myelin during the second decade (Yakovlev & Lecours, 1967; Benes, 1989; Klingberg et al., 1999).

Continued myelination in the frontal cortex during adolescence may cause increased speed of processing in the PFC, and be a basis for gradual development of prefrontal functions (Klingberg et al., 1999), during this time. This maturational event may therefore have important implications for social cognitive abilities that rely on this brain region, such as mentalising, empathy, and emotion processing, over the course of adolescence.

1.5.1.2 Synaptic reorganisation

A second maturational event to occur in the PFC during adolescence is synaptic reorganisation. In a series of post-mortem studies, Huttenlocher (1979) reported that a proliferation of synapses occurs in this region during the first year of life, followed by a period of stability between one and seven years. Synaptic density in the PFC peaks at around age 10 years, and then gradually declines throughout adolescence (age 10-18 years). Synaptic reorganisation in the PFC contrasts to other regions of the brain where this process occurs more rapidly. For example, in the auditory cortex synaptic density reaches its maximum near age three months and is completed by age 12 (Huttenlocher & Dabholker, 1997). The difference in synaptic density patterns across age for the PFC compared to the auditory cortex is presented in Figure 1.3. The later peak in synaptic density in the PFC relative to the auditory cortex reflects the continued proliferation of synapses in this brain region, and its decline into adolescence and young adulthood in the PFC reflects continued pruning of excess synaptic contacts. In contrast, little change in synaptic density occurs after age 12 in the auditory cortex.

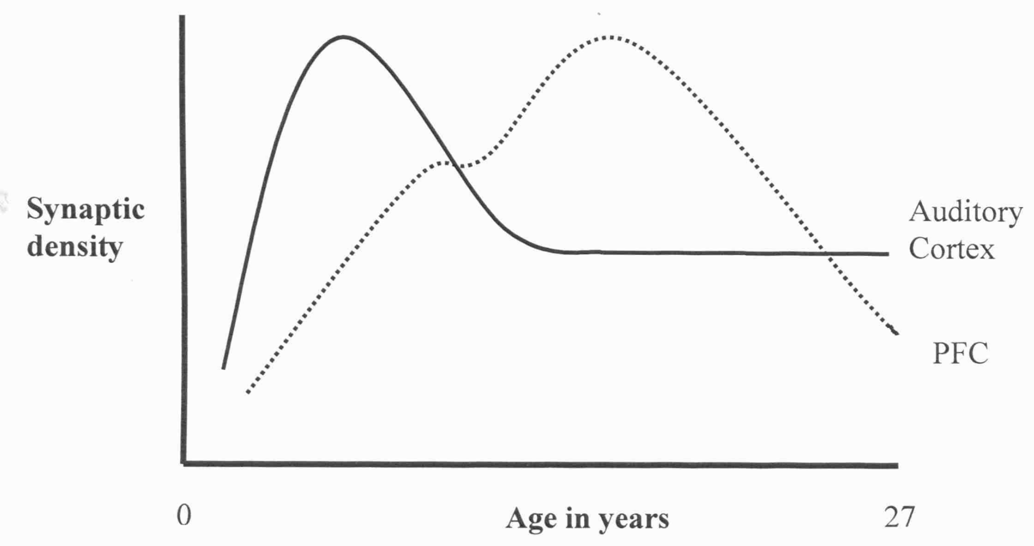

Figure 1.3: Diagram of mean synaptic density in prefrontal and auditory cortices across age, adapted from Huttenlocher & Dabholkar (1997). Synaptic density peaks at a later age in the PFC than in the auditory cortex, and shows continued decline (pruning) into adolescence and young adulthood. Due to the association between the PFC and social cognitive abilities, such events may affect mentalising, empathy, and emotion processing during this time.

Synaptic reorganisation is a non-linear process, as an initial proliferation of synapses in the brain is followed by excess synapses being pruned away. It is thought to strengthen connections between frequently used neurons, while infrequently used connections are gradually pruned away. This process therefore fine-tunes connectivity between neurons, increasing the efficiency of brain networks in developing regions (Blakemore & Choudhury, 2006). For example, sound categorisation in the auditory cortex during infancy is thought to be driven by synaptic reorganisation. While newborn infants are able to discriminate all speech sounds, this ability becomes restricted to only those to which they had been exposed to during the first 12 months of life (Kuhl et al, 1992; 2004). This may reflect the strengthening of synaptic connections processing familiar sounds during the first year of life and the pruning or loss of connections that are less frequently used due to lack of exposure during this time (Blakemore & Choudhury, 2006).

Both myelination and synaptic reorganisation may therefore lead to an increased efficiency of cortical connectivity in the frontal cortex during adolescence. Given the association between the frontal cortex and social cognition, such increased brain connectivity may impact on the abilities investigated by this thesis during adolescence.

Structural imaging studies have found linear increases in white matter (WM) and non linear changes in grey matter (GM) density occurring in brain regions including the frontal cortex during adolescence. These changes probably reflect myelination and synaptic reorganisation, respectively. Studies demonstrating protracted development of brain regions associated with social cognition are presented in the next section.

1.5.2 Brain development during adolescence: magnetic resonance imaging (MRI) studies

MRI creates structural images of the brain using nuclear magnetic resonance. These images can be collected over time from the same individual(s) in longitudinal studies that track developmental change in the brain over age. Development may also be observed from comparing MRI images taken at one time point from a number of participants of different ages, as in cross-sectional research. WM reflects myelinated axons, which appear white in MRI. In contrast, GM reflects unmyelinated structures such as cell bodies and synapses. Higher volumes of WM and lower volumes of GM have been found in adolescents aged 14 compared with children aged nine years (Sowell et al., 1999). This suggests that an increase in WM density, and a decrease in GM density, occurs between childhood and adolescence in brain regions important for social cognition. While these processes happen during similar time periods, studies demonstrating WM and GM change during childhood and adolescence are presented separately for clarity.

1.5.2.1 White Matter (WM)

Giedd et al. (1999) conducted a large-scale longitudinal paediatric study involving 145 healthy volunteers whereby all were scanned at least once, and 98 were scanned twice or more at approximately two-year intervals. The data indicated linear increases in total WM volume between the ages of 4.2 and 21.6 years. This is consistent with other studies (see Paus et al., 2005 for a review), and with the continued myelination occurring in the frontal cortex during this time as found in studies by Yakovlev and Lecours (1967), and Benes (1989). In addition, in a cross-sectional study of 85 children aged between five and 17 years old, Reiss et al. (1996) found the greatest increase in WM density to be in the PFC. These linear WM increases during adolescence are thought to reflect myelination, as WM reflects myelinated axons of neurons in MRI, which follow a linear trajectory of maturational change during this time (see Section 1.5.1.1). Linear development of total WM density across age is illustrated in Figure 1.4.

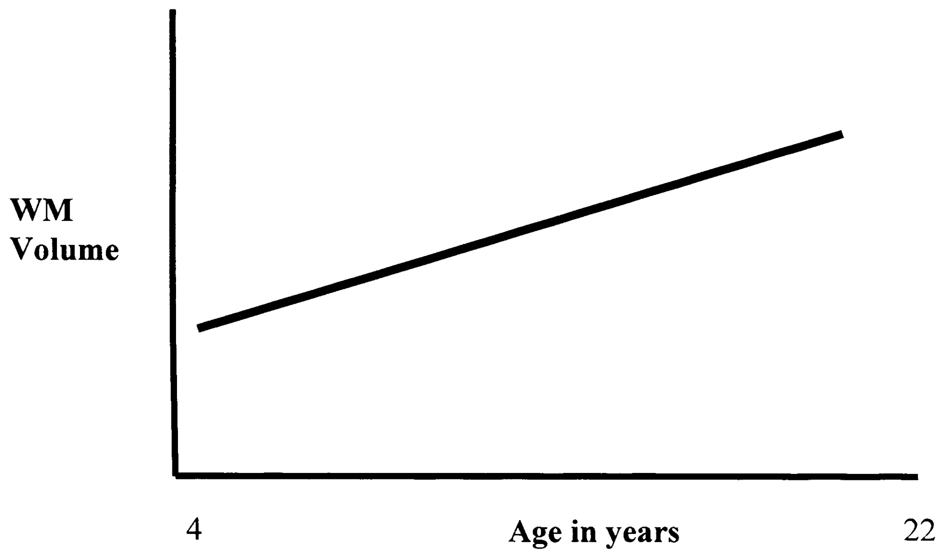

Figure 1.4: Diagram of linear increase in total WM volume between ages four to 22, adapted from Giedd et al. (1999). Reiss et al. (1996) found particularly pronounced WM increase in the PFC, in a sample of participants aged five to 17 years.

1.5.2.2 Grey Matter (GM)

In contrast to the linear increase in total WM volume during adolescence, GM density follows a non-linear trajectory, such that an increase in GM density is followed by a stabilisation and then a gradual decline (e.g. Giedd et al., 1999; Gogtay et al., 2004; Sowell et al., 1999; 2001; 2002; 2003). In addition, this pattern of GM change is regionally specific. For example, GM density has been found to peak around age 12 years in the frontal and parietal lobes, and at age 16 in the temporal lobes, followed by a decline to age 22 (Giedd et al, 1999). This decline is most dramatic between adolescence and adulthood in the frontal lobes (Sowell et al., 1999; 2001). Sowell et al. (2001) found that while little brain growth occurred between seven and 16 years, GM density in the dorsal frontal cortex underwent a significant reduction (9%) in GM density between adolescence and adulthood (age 23-30 years). In regions such as the

STS, the decline in GM density occurs more gradually (Gogtay et al., 2004; Toga et al., 2006). Such non-linear changes in GM density into early adulthood are thought to reflect synaptic reorganisation, as GM reflects unmyelinated structures in MRI, such as synapses that follow a non-linear trajectory of maturational change during this time (see Section 1.5.1.2). These findings emphasise the protracted development of the frontal cortex, associated with social cognitive abilities, relative to other brain regions during adolescence. The non-linear trajectory of GM density in the frontal lobes across age is illustrated in Figure 1.5.

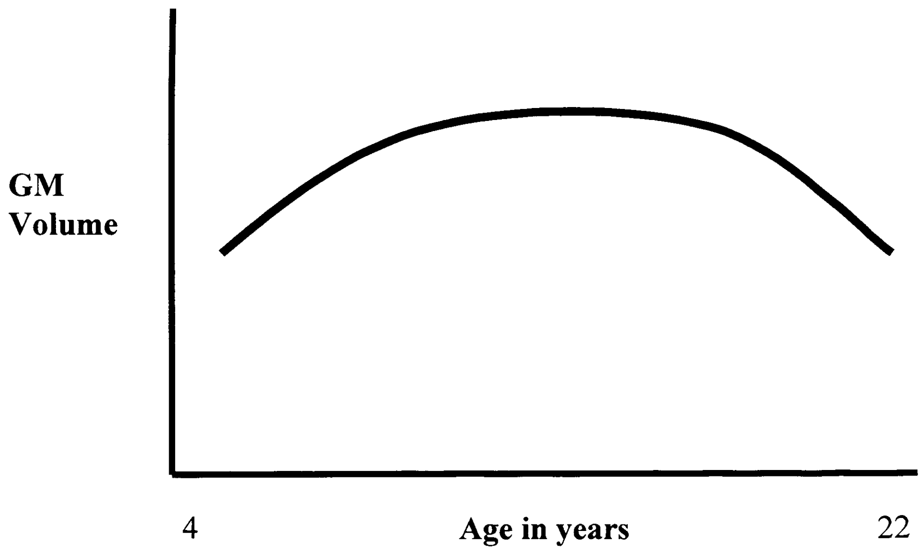

Figure 1.5: Diagram of GM volume in frontal cortex, adapted from Giedd et al. (1999). The increased GM density found during early childhood stabilises during adolescence and begins to decline dramatically into early adulthood (Sowell et al., 1999; 2001). Regions of the temporal cortex including the STS also follow this inverted U-shaped developmental curve, but show a more gradual course, peaking later in adolescence (around the age of 16) and reaching maturity relatively late (Toga et al., 2006).

The continuation of these developmental events into adolescence and young adulthood is consistent with cortical development following a sequence of functional maturation, in which areas associated with more basic functions (e.g. vision) mature before areas associated with more complex functions (e.g. speech and language) (Sowell et al, 1999). For example, the primary sensorimotor cortices mature before the superior temporal cortex (Gogtay et al, 2004). In addition to the visual and auditory cortices, primitive brain regions such as the brain stem and cerebellum mature earlier than more complex regions such as the frontal lobes (Sowell et al, 1999). The impact of this development on the way the brain processes information over the course of childhood and adolescence is considered in the next section.

1.5.3 Brain development during adolescence: functional MRI Studies

Functional MRI (fMRI) measures haemodynamic responses related to neural activity. Consistent with dramatic maturational change in the frontal cortex during adolescence (Huttenlocher, 1979; Sowell et al., 1999; 2001), research has indicated increased activation of the PFC between childhood and adolescence (Killgore et al., 2001; Yurgelun-Todd & Killgore, 2006). Killgore et al. (2001) presented 19 children and adolescents aged from nine to 17 years with pictures of fearful faces in an fMRI scanner. The results indicated that, for females only, increased activation in dorsolateral PFC occurred in response to fearful faces with age (Killgore et al., 2001). This is consistent with a later study by Yurgelun-Todd and Killgore (2006) whereby increased PFC activity in response to fearful faces was found between the age of eight and 15. Activation of the PFC has been found to decrease between adolescence and adulthood (Monk et al., 2003; Blakemore et al., 2007). Monk et al. (2003) presented adolescents and adults with pictures of faces showing fearful or neutral facial expressions. When directed to attend to the subjective emotional experiences displayed in the fearful faces, greater activation in the orbital frontal cortex was found in adults relative to adolescents. When attention was unconstrained, i.e. items were passively viewed without any instruction, greater activity in the anterior cingulate, the orbitofrontal cortex, and right amygdala, was found in adolescents compared with adults while viewing the fearful relative to neutral faces. Adults may therefore show greater modulation of PFC activity based on attentional demands, whereas adolescents exhibit greater modulation based on emotional content, demonstrating an immaturity in attention-related brain activation in adolescents on this task (Monk et al. 2003).

Changes in activation of the PFC between childhood and adulthood emphasise the protracted nature of development of brain regions associated with social cognition. The development of executive functions will now be discussed as an example of how development of the PFC may affect cognition associated with its function.

1.5.4 Association between development of the frontal cortex and associated cognitive abilities during adolescence: Research on executive function.

Executive function (EF) refers to the ability to formulate and maintain goal-directed behaviours (Luria, 1966). These abilities are associated with the PFC (Goldman-Rakic et al., 1996) and show development during adolescence (e.g. Casey et al., 1997; Anderson et al., 2001; Luna et al., 2001; Tamm et al., 2002), consistent with the protracted development of this region into young adulthood (e.g. Giedd et al., 1999). For example, using a variety of EF tasks, Anderson et al. (2001) found age-related improvement between the age of 11 and 17 years. This development is consistent with the linear progression of WM, thought to reflect myelination, in regions of the brain including the PFC during adolescence. In addition, a number of studies have also found non-linear development of abilities pertaining to EF (McGivern et al., 2002) and face recognition (Carey et al., 1980; Diamond et al., 1983) during adolescence. This developmental trajectory has been attributed to changes in GM, thought to reflect synaptic reorganisation, in the frontal lobes during this time. For example, McGivern et al. (2002) found that performance on a match-to-sample type task improved up to age 10, then decreased before stabilising at age 15. Carey et al. (1980) presented 160 female participants between the ages of six to 16 years with a face-encoding task. The results indicated that while performance improved steadily between the ages of six to 10, the ability to encode faces remained constant or even declined for several years (around the onset of puberty), improving again at age 16 (Carey et al., 1980). These results are consistent with a later study by Diamond et al. (1984), whereby pubescent females demonstrated less efficient face encoding than pre- or post- pubescent females. These cognitive changes appear to be consistent with maturational events occurring in the frontal lobes during adolescence and suggest an association between cortical development and cognition, which could also be found for social cognitive processes during this time.

1.5.6 Gender Differences

While there are gender differences in the timing and rate of pubertal development (Grumbach & Styne, 1998), the trajectory of maturational processes in the brain has not been found to differ significantly between males and females during development (Giedd et al., 1999). As the investigation of gender differences in social cognition during adolescence was beyond the scope of this thesis, this topic will not be further discussed.

1.5.7 Summary: Puberty and adolescence

Research has indicated continued maturation into adolescence of brain areas associated with social cognition in adults, such as the PFC and STS. Brain maturation during childhood has long been associated with cognitive development during this time. However, research indicating that cortical development continues into adolescence suggests that further cognitive change may occur during this time. While this has been researched by a number of studies investigating the development of EF, and these data have been consistent with both linear WM increases (e.g. Anderson et al., 2001) and nonlinear GM change (e.g. McGivern et al., 2002) in the frontal lobes during this time (e.g. Giedd et al., 1999; Sowell et all., 1999), little research has focused on the development of *social* cognition in adolescence. It may be that abilities such as mentalising, empathy, and emotion processing are also affected by progressive (myelination) and regressive (synaptic reorganisation) maturational events occurring in these regions during this time. The small number of studies available to date that have done so are discussed the final section.

1.6 Social Cognition in Adolescence

1.6.1 Mentalising in adolescence

The ability to mentalise may play an increasingly important role in successful social interactions with peers during late childhood and adolescence. For example, Bosacki and Astington (1999) looked at the way children aged 11.5 years understood social situations by presenting 128 male and female subjects with short stories involving various scenarios containing people interacting with each other. A positive association between social understanding (mentalising scores) and ratings from peers of subjects' social-interaction skills was found, suggesting that pre-adolescents who were more competent at mentalising were also more socially competent (Boysacki & Astington, 1999). This research highlights the role played by mentalising in social interaction during adolescence (O'Connor & Hirsch, 1999).

In addition, imaging research has indicated that adolescence may be a time of heightened activity in the PFC relative to childhood (Moriguchi et al., 2007) and adulthood (Blakemore et al., 2007) on tasks requiring mentalising. Using an animations task similar to that already described (see section 1.2.1), Moriguchi et al. (2007) found a positive correlation between activation of the mPFC and age in children aged between nine and 16 years. Greater activation was therefore found in the PFC during adolescence than childhood. Blakemore et al. (2007) presented adolescents and adults with a task involving answering questions that either required intentional, or physical, inferences. Significantly greater activation of mPFC in adolescents compared to adults during the intentional vs. physical condition was found. Furthermore, this activity was negatively correlated with age. In contrast, significantly greater activation of the right

STS was found in adults relative to adolescents. The 'neural strategy' for thinking about intentions may therefore change during adolescence, such that a reliance on more anterior (medial prefrontal) brain regions shifts to more posterior (temporal) brain regions during this time (Blakemore et al., 2007).

1.6.2 Empathy in adolescence

Empathy during adolescence has mostly been investigated through the examination of prosocial behaviour, such as helping people. To act pro-socially toward other people you are assumed to feel some level of shared experience, as you understand that they need your help and are sufficiently moved by this emotion to offer assistance. Being less egocentric and demonstrating prosocial behaviour is also considered to be a mark of maturity by adolescents and young adults across a wide range of cultures (Mayseless & Scharf, 2003; Arnett, 2003). For example, Eisenberg et al. (2005) studied the responses of 32 adolescents' self-report measures of prosocial responding, empathy-related responding and prosocial moral reasoning every year between the ages of 15 and 26 years. The measures assessed various characteristics such as tendency to help other people (prosocial responding), sympathy for others (empathy) and prosocial moral reasoning (justification of behaviour based on whether they were 'right or wrong' in a moral sense, e.g. whether it is morally 'better' to help teach disabled children to swim than to train to compete in a swimming race yourself). The data indicated a linear increase in self-reflective, empathic reasoning with age (Eisenberg et al., 2005). These studies indicate that a shift toward more mature empathic responses develops during adolescence, consistent with protracted cortical development during this time. Similar changes may be found in emotion processing.

1.6.3 Emotion processing in adolescence

Improvements in the ability to recognise emotional facial expressions occur between the ages of nine and 19 years (Pine et al. 2004). Increasing emotional complexity, such as the ability to regulate emotion on the basis of social relationships and inter-personal consequences of behaviour, occur between the ages of 12 and 18 (Zeman et al, 2006). For example, around age 16 adolescents rate their relationships to peers as significantly higher than to their parents (Bieseker, 2001) and are more likely to express emotion when expecting a positive reaction from others (Fuchs & Thelen, 1988; Zeman & Garber, 1996). In addition, more complex experiences relating to social emotions such as embarrassment may increase during this time (Elkind & Bowen, 1979).

Puberty may be a pivotal time for emotional change, followed by a gradual stabilisation through to late adolescence (Larson et al. 2002). Williams et al. (2006) found highest levels of neuroticism in adolescents aged 12-14 years in a sample of participants aged between 12 and 79 years. Alterations in personal identity (Erikson, 1986) as well as increased feelings of distress (Freud, 1946; Gurian, 1996) are also reported during this period. In addition to employing a neuroticism scale, Williams et al. (2006) also presented participants aged between 12 and 79 with a series of photographs of human faces depicting positive and negative emotions. Recognition of emotion was found to change over this age range, such that recognition of happiness improved and fear declined with age. In addition, imaging data from this study indicated an age-related decrease in activation of the mPFC during the early (within 150ms of stimulus presentation) processing of happy faces. In contrast, an age-related increase in mPFC activation was found for later (200ms after stimulus presentation) processing of fearful faces. Williams et al. (2006) suggested that this may reflect a shift from early, automatic emotional responses toward happiness to a later, more controlled processing of fear, with age. Therefore, more restrained responses to negative stimuli as well as unrestrained responses to positive stimuli may occur during this time (Williams et al., 2006). With age then may come a more adaptive manner of emotion processing. However, as with mentalising and empathy, there are few empirical studies to date investigating the period of adolescence as a time of specific change in emotion processing.

1.6.4 Summary: Social cognition in adolescence

Research investigating the nature of mentalising, empathy, and emotion processing, during adolescence has indicated that development occurs during this time. This is consistent with the protracted development of brain regions such as the frontal lobes, in particular the PFC, during adolescence. However, the field of social cognitive neuroscience is relatively new, and little empirical research exists as to the impact continued development of regions such as the frontal and temporal cortices may have on social cognition during adolescence. This thesis aimed to provide a series of behavioural studies to address this research question.

1.7 Overall Summary

The studies in this thesis sought to test the hypothesis that development of aspects of social cognition, namely mentalising, empathy, and emotion processing, may occur during adolescence. This hypothesis was generated from research indicating that areas of the brain associated with social cognition, in particular the PFC, showing protracted development into adolescence. In addition, adolescence is a period of significant physical, social, and emotional change. While the developmental trajectories of mentalising, empathy, and emotion processing are well documented in childhood, their neural correlates well studied in adults, and much research has focused on the nature of their impairment in ASD, there has been little work investigating these aspects of cognition in adolescence. A number of novel tasks were developed in order to investigate the development of social cognition in adolescence. In addition, due to mixed reports of mentalising and emotion processing in ASD, these two aspects of social cognition were also investigated in ASD.

1.8 Aims and Predictions

The aim of the studies in this thesis was to investigate mentalising, empathy, and emotion processing during adolescence. In addition to using adapted versions of tasks from previous studies of social cognition by other researchers, a number of novel tasks were developed for use in this thesis. For each experimental study involving adolescents, a hypothesis of change was made such that performance would follow one of two possible patterns. On the one hand, a linear trajectory of social cognitive development during adolescence would be found if social cognition is affected by myelination and its associated increase of WM during this period. In contrast, there might be an inverted U shaped (non-linear) trajectory of social cognitive development if social cognition is affected by synaptogenesis and its associated change of GM during adolescence. The direction of change for each study investigating social cognition during adolescence therefore included analysis of the direction of change during this time. In addition, pubertal stage rather than chronological age was used rather than chronological age on the basis of evidence that pubertal hormones crucially affect brain development and behaviour (e.g. Romeo, 2003) and that maturation is only indirectly related to age (Wetzel, 1941; Krogman, 1950). Investigation of mentalising and emotion processing in ASD, a developmental disorder characterised by impaired social cognition, was also included (Chapters 1 and 8). This was to enable validation and further exploration of paradigms involved in the novel mentalising and emotion tasks developed in this thesis, as well as to provide novel data to the mixed literature regarding impairment of mentalising and emotion processing in ASD.

Chapter 2

INVESTIGATION OF MENTALISING IN ADULTS WITH AUTISM SPECTRUM DISORDER

2.1 Impaired mentalising in autism spectrum disorder

Autism is a developmental disorder characterised by abnormalities of social interaction, impoverished verbal and non-verbal communication and restricted interests/repetitive behaviour (DSM-IV, 1994). The severity of symptoms in autism can range from highly impaired, combined with an IQ lower than 70, to relatively high functioning, combined with average to high IQ, and this continuum is referred to as Autism Spectrum Disorder (ASD; Wing, 1996) - See section 1.4 of Introduction. Children with ASD show an impaired ability to understand the mental states of other people (Theory of Mind, Premack & Woodruff, 1978; or mentalising, Frith & Frith, 2003). While typically developing (TD) children correctly infer that another person has a false belief at around age four (Wimmer & Perner, 1983; Perner & Wimmer, 1985), children with autism typically fail this kind of task, showing an impairment when required to make inferences about the mental state of a story character but not on control tasks (Baron-Cohen et al., 1985). Other studies have also shown impaired performance on tasks requiring mentalising. Baron-Cohen et al. (1999b) found that children with ASD, relative to TD children, were impaired at recognising when a faux pas, or a social transgression, had been made.

Difficulties with inferring the thoughts and beliefs of other people have also been reported in adults with ASD. For example, adults with ASD showed impaired performance on a mentalising task involving stories depicting everyday interactions (Strange Stories; Happé, 1994). This task involves the presentation of 30 short vignettes, each with a picture and two test questions: a comprehension question ('Was it true, what X said?') and a justification question ('Why did X say that?'). In 24 of the vignettes, a mental state inference was required to answer the justification question. The other 6 vignettes consisted of control physical stories in which mental state inferences were not required. Individuals with ASD, relative to control participants, were impaired at providing context-appropriate mental state explanations of the events presented in the vignettes requiring mentalising (e.g. Happé, 1994). Impaired ability at inferring intention and other mental states from eye gaze (Baron-Cohen et al., 1997a;b; 2001a) and tone of voice (Rutherford et al., 2002) have also been found in individuals with ASD.

2.2 Challenges to the existence of impaired mentalising in ASD

A number of studies have failed to find impairments on mentalising tasks in individuals with ASD. For example, Russell and Hill (2001) found intact reporting of other people's intentions by children with ASD relative to children with moderate learning disabilities and TD children, matched for verbal age. In addition, between 15% and 55% of individuals with autism are able to pass 'first order' false belief tests (Happé & Frith, 1996). These findings pose difficulties for a theory of ASD that relies purely on a mentalising deficit. Research by Tager-Flusberg and Sullivan (1994) and Sullivan et al. (1994) suggests that individuals with ASD may fail mentalising tasks due to the advanced information-processing abilities required by these tasks, rather than an inability to infer the mental states of others. For example, by simplifying the task material (i.e. decreasing the length, complexity, and format of stories), Sullivan et al. (1994) found that almost half of participants with ASD could provide adequate mental state descriptions. In addition, using the same task stimuli, Tager-Flusberg and Sullivan (1994) found no differences between individuals with ASD and a control group of matched mentally retarded (MR) participants in mentalising ability. These results are contrary to other research finding specific mentalising deficits in ASD relative to matched MR controls (e.g. Baron-Cohen at al., 1985; Ozonoff et al., 1991).

2.3 Possible influences on performance during mentalising tasks in ASD

The distinction between individuals with ASD who pass mentalising tasks and those who do not is not clear. Tager-Flusberg et al. (2001) report that the ability to provide adequate explanations of other people's mental states in ASD has been found to be closely related to language ability, and it may therefore be that individuals with ASD who are successful on mentalising tasks tend to be older and more verbal (Happé et al, 1994). Another possibility is that individuals with ASD who pass mentalising tasks use cognitive strategies other than mentalising, or are a subset of the ASD population with distinct aetiology (Happé & Frith, 1996). Thus, while the social abilities of adults with autism are often impaired, empirical research on their mentalising abilities has been inconsistent, with some studies demonstrating impairments and other studies demonstrating intact performance on mentalising tasks.

2.4 Investigation of mentalising in ASD using a novel mentalising task

The aim of the current study was to investigate the nature of the mentalising deficit in a group of adults with ASD using response time as the dependent measure. A novel task was designed that was based loosely on Happé's (1994) Strange Stories (see section 1.2.1 of Introduction). Due to previous research indicating that language may affect performance on mentalising tasks in ASD (Tager-Flusberg & Sullivan, 1994; Sullivan et al., 1994), the current task had reduced language requirements as it did not rely on a verbal response from participants. Instead, a short scenario was presented on a computer screen and followed by a question and three multiple choice answers. Participants were asked to select a correct response. There were three conditions: i. *Mentalising,* in which a mental state inference was required to select the correct response; ii. *People-non-mentalising,* in which an inference about people, but not mental states, was required; iii. *Physical,* in which an inference about physical, natural events was required. Both accuracy and time taken to respond to the question was recorded. On the basis of mixed findings as to the existence of a mentalising impairment in ASD, two hypotheses were generated. First, compared with matched control participants, individuals with ASD would show impaired performance on stories requiring the attribution of mental states (mentalising) compared with the two control conditions in which no mental state inference was required. Alternatively, individuals with ASD and matched control participants might perform at a comparable level in all three conditions, consistent with no mentalising deficit in ASD.

2.5 Method

2.5.1 Participants

16 adults with ASD (14 males; mean age 39.31 years±3.87, range 18.02-55.03 years) and 15 matched controls (13 males; mean age 36 years±2.92, range 24.10-61.09 years) took part in the present study. Participants were recruited through letters and emails, and gave their written informed consent to take part in the study, which was approved by the local ethics committee. Participants were paid £7.50 per hour for taking part in the study.

Participants in the ASD group had all been diagnosed with ASD and their diagnosis was confirmed using The Autism Diagnostic Observational Schedule-G (Lord et al., 2000). IQ was tested using the Wechsler Adult Intelligence Scale (Wechsler, 1997) for all individuals with ASD and 4 controls (NCs) and the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1997) for 11 NCs. Verbal and nonverbal IQ was not available for 4 NCs. Participant details can be found in Table 2.1. No significant differences were found between the ASD and NC groups for age or IQ.

Group	Mean Age (±SEM)	Mean Full Scale IQ (±SEM)	Mean Verbal IQ (±SEM)	Mean Nonverbal IQ (±SEM)	Mean full-Scale ADOS (±SEM)
ASD (*n*=16, 15 males)	39.31±3.87	113.56±4.47	115.56±3.93	107.81±4.97	11.5±0.92
NC (*n*=15, 13 males)	36±2.92	117±3.51	110.64±3.09	111.36±3.43	N/A
Group comparison	$t(29)=.612$, $p>.05$	$t(29)=.955$, $p>.05$	$t(25)=.988$, $p>.05$	$t(25)=-..331$, $p>.05$	N/A

Table 2.1: Participant details. Verbal and nonverbal IQ was not available for 4 NCs.

2.5.2 *Design*

A novel computerised task was designed in which short scenarios were presented on a computer screen. Participants were asked to read the scenario and, once they had understood it, to press the space bar. This elicited the presentation of a question and three multiple choice answers below the scenario. The scenario remained on the screen to avoid participants having to rely on memory. Participants were asked to select a correct response to the question by using three highlighted keys on the computer keyboard (A, S or D corresponding to the answer on the left, middle or right). The next scenario was presented following selection of an answer. The time from when the scenario appeared on the screen to when the participant pressed the space bar was recorded as their 'reading time'. Reading time data were used to eliminate outliers from the analysis. The time from when the question and answers appeared on the screen, to when a response was selected was recorded as their 'response time'. The response selected for each question was also recorded.

There were three conditions: i. *Mentalising:* the scenarios involved people and a mental state inference was required to select the correct response; ii. *People-non-mentalising:* the scenarios involved people but no mental state inference was required to select the correct response; iii. *Physical*: the scenarios involved physical, natural events (no people) and an inference about the physical world was required to select the correct response. For examples of the stimuli in each condition see Appendix B.

A total of 30 stories (10 of each condition) were presented. Within each story, the order of multiple choice responses was pseudorandomised such that the position of the correct response was counterbalanced between conditions. There were four blocks of stories: two blocks of seven and two blocks of eight. Story type was randomised across blocks. Within each block, condition order was pseudorandomised such that the same condition did not occur more than twice in a row. Participants sat at a desk and the task was presented on a laptop computer (see Figure 2.1).

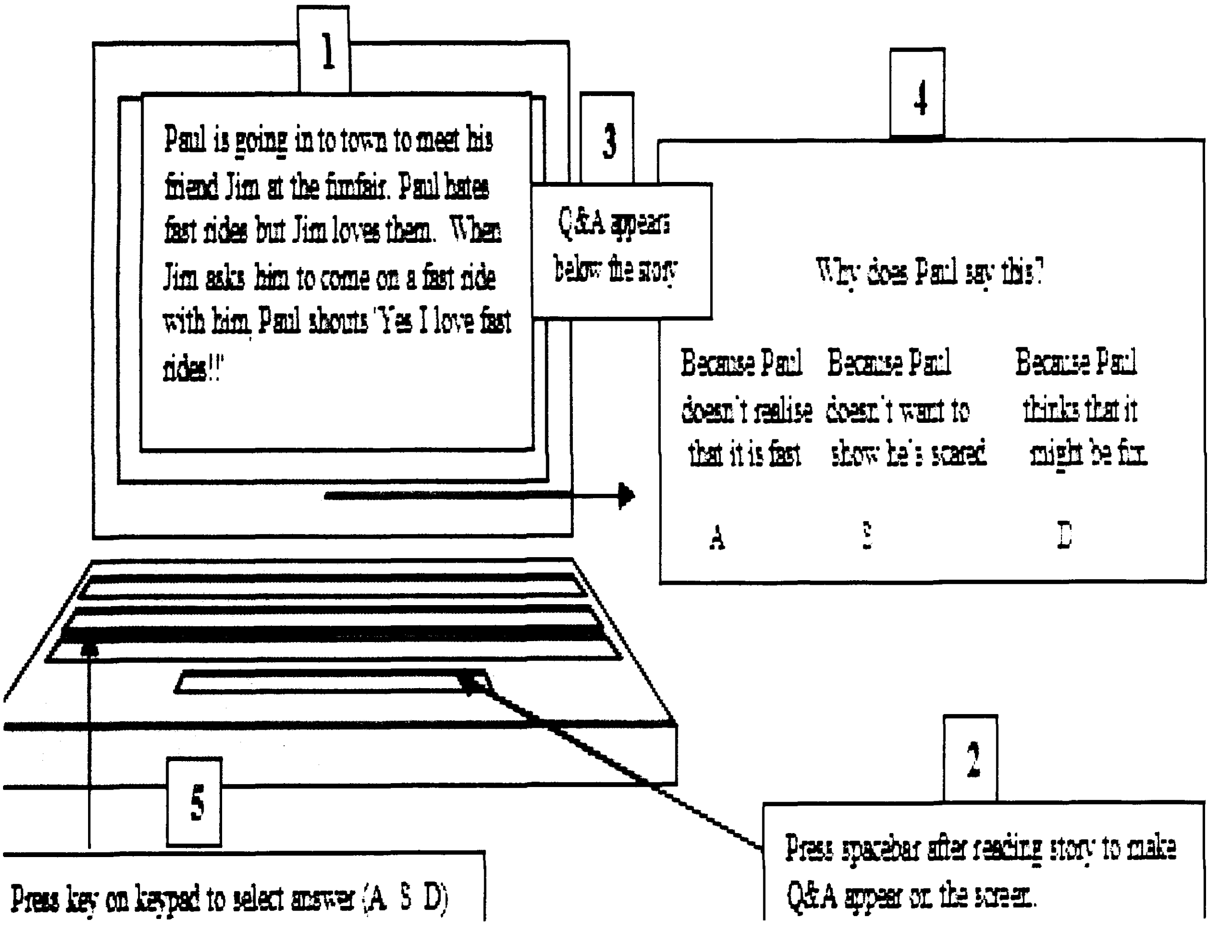

Figure 2.1: Diagram of task with an example of a mentalising story. Task procedure is marked from 1-5.

2.5.3 Analysis

To access accuracy, the total number of errors out of 10 was calculated for each participant in each condition. To assess response time, median response time was calculated for each participant for each condition. For both error rate and response time, the difference in mean performance of each group in the three conditions was analysed using ANOVA with between-subjects factor of *Group* (ASD or control) and within-subjects factor of *Condition* (Mentalising, People non-mentalising, Physical). Full-scale IQ was entered into these analyses as a covariate to control for any combined effects of verbal and non-verbal IQ on performance. Post-hoc simple effects analyses were used to investigate any significant effects or interactions revealed by the ANOVA.

2.6 Results

There were no outliers based on reading time. No significant differences between individuals with ASD and controls were found for accuracy on the task ($p>.05$).

2.6.1 Response time

The mean response time in each condition for both groups is shown in Figure 2.2. ANOVA revealed a significant interaction between group and condition ($F_{(2,56)}=5.291$, $p<.05$). There was no significant main effect of condition ($F_{(2,56)}=.269$, $p>.05$) or of group ($F_{(1,28)}=.715$, $p>.05$).

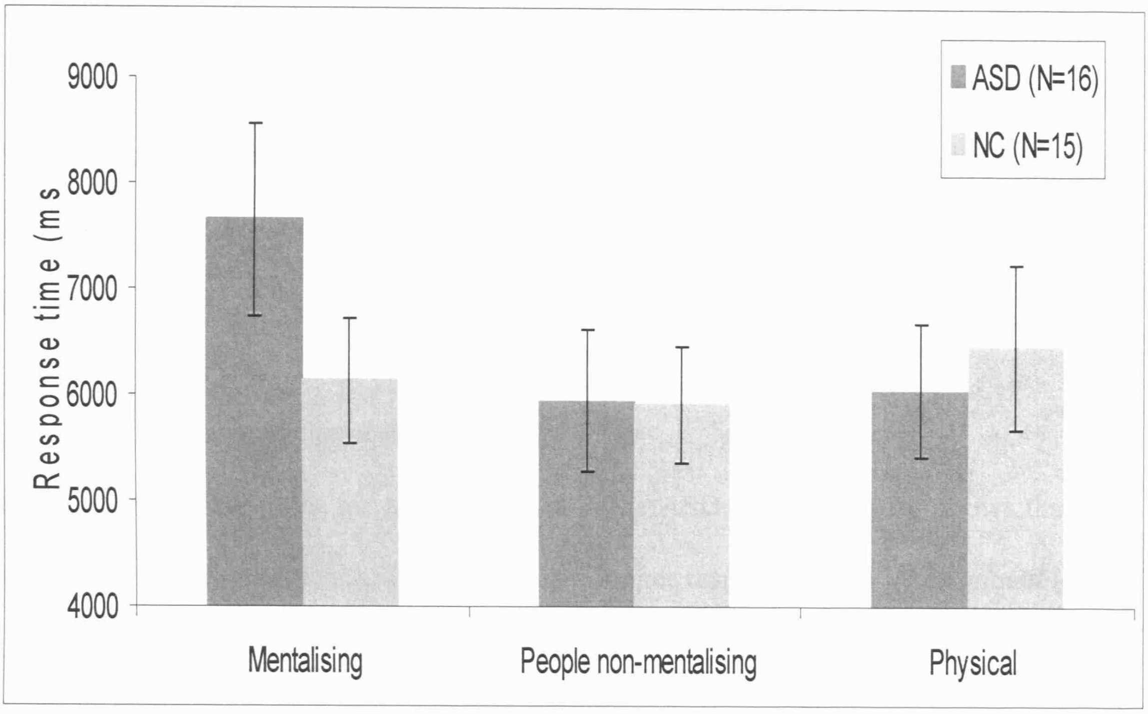

Figure 2.2: Between-group comparison of response times for each condition, showing significantly longer response time in the mentalising condition relative to the two control conditions for the ASD group compared to the NC group.

2.6.1.1 Between-subjects comparison

Post-hoc between-subjects simple effects revealed that the ASD group demonstrated significantly longer response times than the NC group in the mentalising condition ($p<.05$, 1-tailed). No significant differences in response time were found between ASD and NC in the control conditions (people non-mentalising: $p>.05$; physical: $p>.05$).

2.6.1.2 Within-subjects comparison

Post-hoc within-subjects simple effects revealed that the interaction was driven by significantly slower response times in the mentalising condition than in the other two conditions for the ASD group (mentalising vs. people non-mentalising for ASD group:

p<.0001; mentalising vs. physical for ASD group: p<.005). No significant difference between the two control conditions was found for the ASD group (people non-mentalising vs. physical for the ASD group: p>.05). There was no significant difference in response time between any of the conditions for the NC group (all comparisons for NC group: p>.05).

2.6.1.3 Individual participant data

Individual response times for each condition in the ASD and NC groups shows that 13 out of 16 participants with ASD demonstrated longer response times in the mentalising condition than in both of the other two conditions. In contrast, only 4 out of 15 NC participants demonstrated longer response times in the mentalising condition than in both of the other two conditions. This difference between groups was significant (X^2=7.24; p<.001).

2.7 Discussion

This study aimed to investigate mentalising in individuals with ASD compared with matched control participants using a novel computer task based on the Strange Stories paradigm (Happé, 1994). The task consisted of three conditions: i. *Mentalising*, in which mental state inferences were required to select a correct response; ii. *People non-mentalising*, in which inferences about people but not mental states were required to select a correct response; and iii. *Physical scenarios*, in which no people were present and inferences about physical, natural events were required to select a correct response. While individuals with ASD showed high accuracy on all three conditions, the results showed that they took a longer time to respond to scenarios requiring an inference about the mental states of other people compared with scenarios in which mental state inferences were not required. This was in contrast to matched control participants who showed no difference in response time between conditions. In addition, individuals with ASD demonstrated significantly longer response times than control participants in the mentalising condition, but not in the control conditions.

2.7.1 Impaired mentalising in ASD on the computerised task

Data is consistent with previous research indicating difficulty in inferring the mental states of other people in ASD (e.g. Baron-Cohen et al., 1985; 1997a;b; 1999b;c; 2001a; Happé et al., 1994; 1996; Rutherford et al., 2002). For example, Baron-Cohen et al. (1999b) found that children with ASD are impaired relative to controls at recognising faux pas. Adults with ASD demonstrate impaired ability at inferring intentions from pictures of other people's eyes (Baron-Cohen et al., 1997a;b; 2001a) and vocalisations (Rutherford et al, 2002). However, other studies have found no such impairments in ASD (e.g. Tager-Flusberg & Sullivan, 1994; Sullivan et al., 1994). Tager-Flusberg and Sullivan (1994) found no impairment in ASD relative to matched MR controls on a mentalising task with lower information-processing demands. In addition, the ability of individuals with ASD to pass mentalising tasks has been linked to language ability (Tager-Flusberg et al., 2001; Steele et al., 2003). Therefore, the literature is mixed on the existence of an account of ASD which is purely focused upon a mentalising deficit. The current findings lend support to the mentalising deficit account of ASD when verbal demands are minimised by using a computerised task in which response time, rather than accuracy, is the key dependent variable.

The current findings contrast with previous research whereby differences in error rate, but not response time, between ASD and controls have been found (e.g. Happé et al., 1996). It may be that allowing response times of around 40 seconds as in the Happé et al. (1996) study concealed any differences between performance of individuals with ASD and controls. The results of the current study suggest that more sensitive measures of mentalising ability, such as shorter response times (around 6.5 seconds) to make mental state inferences, might be a useful way of investigating mentalising impairment in ASD.

2.7.2 Possible reasons for longer response times to mentalise in ASD

Neuroimaging studies have found atypical activation of social brain areas including the medial prefrontal cortex (mPFC) and superior temporal sulcus (STS) in people with ASD during tasks involving mentalising (Castelli et al., 2002; Happé et al., 1996). For example, Castelli et al. (2002) presented individuals with ASD and controls with an animations task where two triangles were shown moving on a computer screen. There were three conditions: i. mentalising (e.g. coaxing, tricking), ii. goal-directed (e.g. chasing, fighting), and iii. random movement. See section 1.2.1 of the Introduction for full description of this task. Compared with control participants, individuals with ASD showed less activation of the mPFC, STS and the temporal poles in the mentalising relative to the random movement condition. Happé et al. (1996) found an absence in an ASD group of activation in the mPFC during the viewing of stories involving mentalising. Decreased activation of these regions may reflect weaker cortical engagement in ASD of the mentalising network during situations requiring mental state attribution. Happé et al. (1996) found that, while individuals with ASD did not activate the same region of the mPFC as control participants during mentalising, adjacent regions were significantly activated in ASD during mentalising vs. non-mentalising stories. This suggests that individuals with ASD might have developed different cognitive routes to processing stimuli requiring mentalising (Happé & Frith, 1996).

Such functional differences in ASD may manifest as longer response times to situations requiring mental state attribution, as was found in the current study. In other words, while individuals with ASD are able to reach the correct response on mentalising tasks, using a different neural strategy might explain why they take longer to make their responses. Longer response times to situations involving mentalising in ASD may also reflect a lack of automaticity of recruitment of brain regions necessary to understand the social world. During childhood (aged three to four years) individuals with ASD demonstrate impaired social attention skills, such as poor joint attention and social orienting (Dawson et al., 2004). In adults with ASD, this may be reflected by impaired ability to gain information about mental states from other people's eye gaze (e.g. Baron-Cohen et al., 1997a;b; 2001a). Individuals with ASD may therefore not spontaneously think about, or attend to, the thoughts and intentions of other people. However, when required they might be able to use different cognitive strategies, albeit strategies that confer a response time disadvantage, to make mental state attributions.

2.8 Future Directions

The use of imaging technology to investigate the neural correlates of performance on the current task in ASD and normal adults would be of benefit to see if atypical activations during mentalising in ASD seen in other studies (e.g. Happé et al., 1996) are also apparent using the current task. Such data may provide evidence for the different neural strategy behind longer response times in the mentalising condition in ASD.

The development of more ecologically valid mentalising paradigms may enable additional information to be collected regarding the real-life consequences of adults with ASD taking a greater amount of time to mentalise compared with healthy adults. For example, a paradigm developed by Keysar et al. (2003) whereby individuals are assessed on their ability to hide objects from other people. Conversely however, such 'real time' interactions with other people might be a difficult task to employ with individuals with ASD, due to the very nature of ASD being a disorder of marked social difficulties (Frith & Frith, 2003). The use of computer paradigms as in the present study may therefore be best suited to investigating mentalising in this clinical population. Use of the current mentalising task in other fields, such as normative and developmental studies, may also be a consideration for future research. For example, the task could be employed to track the development of mentalising over age in TD individuals.

2.9 Summary

The aim of this study was to use a novel computerised task to investigate mentalising in ASD. Consistent with the hypothesis of a mentalising deficit in ASD as posited by Baron-Cohen et al. (1985), the results of the study revealed that participants with ASD demonstrated significantly longer response times in the mentalising condition relative to control conditions, and matched control participants.

The novel task has several benefits. First, it is relatively quick, taking no longer than 30 minutes for each participant. Second, the computerised nature of the task enables measurement of response times as well as error rate. Third, the use of multiple choice answers is less open-ended than asking participants to make a verbal response. Finally, the inclusion of two control tasks controls for a variety of factors that might influence the results. These include the presence of people in the mentalising condition, which was controlled for by including a condition in which people were present but no mental state inference was necessary. They also controlled for general requirements such as memory load, the need to make a logical inference, concentration and attention, which were necessary for all three conditions. The current data suggest that increased response times on the mentalising condition in ASD was specific to mental state inference, and cannot be explained by other more general cognitive impairments.

As a mentalising deficit in ASD is consistent with past research (e.g. Baron-Cohen et al., 1985; Happé, 1994), this task may be considered a useful measure of the ability to mentalise. Therefore, it was used to investigate whether any changes in mentalising occurred over the course of typical adolescence. This study is presented in the next experimental chapter.

Chapter 3

INVESTIGATING MENTALISING DURING ADOLESCENCE USING A COMPUTERISED STORIES TASK

3.1 Mentalising during childhood

Mentalising (Frith & Frith, 2003) refers to the ability to attribute mental states to the self and others in order to explain and predict behaviour. Some social cognitive abilities appear very early in life, and may be precursors to a coherent mentalising system (Leslie, 1987). For example, joint attention is the ability to share experiences by following other people's eye gaze or gestures, and has been found to develop during the first year (Butterworth & Jarrett, 1991). However, an explicit understanding of the contents of other people's minds does not develop until around age four years, by which time children are able to pass 'false belief' tasks (Wimmer & Perner, 1983; Perner & Wimmer, 1985). False belief tasks typically involve the presentation of a scenario involving an object being hidden out of sight of a character. Understanding that the character will not know that the object has been hidden, i.e. that they have a belief that is different from reality, implies an understanding of the mental states of other people. While children aged four years successfully demonstrate this understanding, three year old children do not, suggesting that early childhood is a crucial time for the development of mentalising (Wimmer & Perner, 1983).

The success of children aged four years on tasks of false belief has resulted in a relative paucity of research investigating mentalising past this age. The few studies that have done so however indicate that further change in this ability may occur into late childhood. For example, improved performance on mentalising tasks (including the false belief paradigm described in section 1.3.1 of Introduction) has been found to occur between the ages of three and six years (Reches & Periera, 2007). Sodian and Schneider (1990) assessed children aged four to six years on their ability to intentionally deceive others by manipulating cues to hide objects. Only children aged six demonstrated consistent success on this task; none of the four year olds and only half of the five year olds were able to do so. This suggests that young children may not always engage in mentalising when interacting with other people, and that mentalising may become a more consistent cognitive strategy over time (Sodian & Schneider, 1990). In addition, it is only by 11 years that children judge people based on their intentions rather than their behaviour (Rotenberg, 1980). Therefore an increasing complexity and utilisation of mentalising appears to develop past age four, into late childhood. However, few studies have investigated the development of mentalising during adolescence.

3.2 Protracted development of the social brain network during adolescence

Imaging research with adults has consistently found activation of the medial prefrontal cortex (mPFC), superior temporal sulcus (STS), and temporal poles bilaterally, during tasks requiring mentalising (Gallagher & Frith, 2003). mPFC and STS show protracted development, with changes in grey matter (GM) volume and increases in white matter (WM) volume occurring in regions including the frontal and temporal lobes, over the course of childhood and adolescence (Reiss et al, 1996; Sowell et al, 2002). These changes are consistent with post-mortem studies that revealed two maturational processes occurring in the same regions found to show change in WM and GM volume on MRI, during adolescence. These processes, namely axonal myelination (Yakovlev & Lecours, 1967) and synaptic reorganisation (Huttenlocher, 1979), are thought to facilitate information processing by increasing the speed of electrical transmission between neurons in developing regions of the brain (Blakemore & Choudhury, 2006). See section 1.5 of the Introduction for full description of maturational processes occurring in the brain during adolescence.

This cellular development may be reflected in functional imaging studies showing increased activation of the frontal, parietal, and temporal lobes during development (Luna et al, 2001; Casey et al, 2000). Increased activation of the PFC has been found between childhood and adolescence (Killgore et al., 2001; Yurgelun-Todd & Killgore, 2006), while decreased activation of the PFC has been found between adolescence and adulthood (Monk et al., 2003; Blakemore et al., 2007). This suggests that adolescence may be a period of heightened activity in the PFC, perhaps as a result of maturational events occurring in the frontal cortex during this time. For example, a second wave of synaptogenesis occurs around the onset of puberty in the PFC (Huttenlocher, 1979). The excess of synapses produced by this process could cause increased cognitive effort, resulting in increased activation of this region on fMRI, during tasks involving this brain region. Change in abilities associated with the PFC, such as mentalising, may occur as a result of such maturation.

3.3 Investigating mentalising during adolescence

There is a paucity of research investigating the impact of cortical development on social cognitive abilities such as mentalising during adolescence. A number of studies investigating executive function (EF), which involves abilities such as memory and planning also associated with the PFC (Goldman-Rakic et al., 1996), have found development consistent with maturational events in this region over the course of adolescence. For example, age-related linear improvement on a number of EF tasks has been found to occur up to age 17 (Anderson et al., 2001; Luna et al., 2001) and 20 (Tamm et al., 2001) years. This is consistent with linear increases of WM found in regions including the PFC during adolescence (e.g. Paus et al., 1999). However, McGivern et al. (2002) found performance on a match-to-sample type task to improve up to around the age of puberty onset, after which it stabilised or even declined, and then continued to improve until reaching adult levels around age 15. This is consistent with a number of other studies involving recognition of faces (Carey et al., 1980; Diamond et al., 1983), and such non-linear patterns of performance are compatible with the trajectory of cortical GM change occurring in frontal and temporal brain regions during adolescence (e.g. Giedd et al., 1999; Toga et al., 2006). Therefore, while studies investigating abilities associated with the frontal lobes have found further cognitive development to occur during adolescence, evidence as to the trajectory of performance during this time is mixed.

Despite a wealth of evidence documenting the development of mentalising during childhood and its neural correlates in adults, little research to date has focused on this ability during adolescence. This was the aim of the current study. Similar to the development of EF over adolescence and consistent with maturational events in the frontal cortex, in particular the PFC, further change was hypothesised to occur in the ability to mentalise during this time. To investigate the developmental trajectory of mentalising during adolescence, a computerised mentalising task was developed based loosely on the Strange Story paradigm of Happé (1994) – for details see Chapter 2. This task involved the presentation of short stories, questions and multiple choice answers on a computer screen. There were three conditions: i. *Mentalising*, in which mental state inferences were required to select a correct response; ii. *People non-mentalising*, in which inferences about people but not mental states were required to select a correct response; and iii. *Physical*, in which no people were present and inferences about physical, natural events were required to select a correct response. Accuracy and response time were used as dependent measures with which a specific change in the ability to mentalise during adolescence was investigated.

Due to the success of children aged around four years on tasks of false belief (e.g. Wimmer & Perner, 1983), it was acknowledged that a dramatic change in the ability to mentalise during adolescence was unlikely. Instead, a subtle change was predicted. However, the pattern of any such change was unknown. Due to mixed reports on tasks such as EF during adolescence (e.g. Anderson et al., 2001; McGivern et al., 2002), two possible developmental trajectories were predicted. First, there may be a linear pattern of improvement in mentalising, consistent with the linear increase in WM reflecting myelination in regions including the PFC during adolescence. However, if the development of mentalising is driven by synaptic reorganisation then there may be an inverted U shaped pattern of development with particular performance impairments during puberty when there is a wave of synaptogenesis in the PFC (Huttenlocher, 1979). As these maturational changes are specific to regions associated with mentalising, changes in mentalising ability may occur over and above general cognitive improvement (as tested by the control conditions). Puberty rather than chronological age was taken as the independent measure, as maturational change is associated with physical development rather than age per se (e.g. Romeo, 2003; Wetzel, 1941; Krogman, 1950). The effect of gender on performance was also investigated, as previous research has indicated a female advantage on mentalising tasks (e.g. Charman et al., 2002; Simpson, 2003; Baron-Cohen et al., 1999b), which persists into adulthood (e.g. Baron-Cohen et al., 1997a;b). Such advantage could be consistent with earlier sexual maturation in females compared with males (Grumbach & Styne, 1998), although the trajectory of maturational processes occuring in the cortex has not been found to differ significantly between males and females during development (Giedd et al., 1999).

3.4 Method

3.4.1 Participants

159 participants (82 male) between the age of 8.08 and 80.01 years took part in the study. On the basis of a standardised developmental questionnaire adapted from Carskadon & Acebo (1993) (see Appendix A), school-aged participants were allotted to one of three groups: pre-puberty (*n* =44, 25 male, mean age 9.06±0.13, range 8.08–11.05 years); mid-puberty (*n* = 47, 23 male, mean age 12.01±1.15, range 9.01-14.09 years) and post-puberty (*n* = 39, 19 male, mean age 14.03±0.15, range 12.06-16.07 years). A group of adults also took part in the study (*n*=29, 15 male, mean age 37.03±2.98, range 21.04-80.01 years).

School aged participants were recruited from schools in South London and on the Isle of Wight and were of similar socio-economic background, with similar school schedules. These participants were recruited through letters sent to the schools that briefly detailed the study and asked for their participation. Both parental and participant consent was obtained before the study, which was approved by the local ethics committee. The British Picture Vocabulary Scale (BPVS; Dunn et al., 1997) was performed with each school-aged participant individually and used as an estimate of verbal intelligence. Standardised scores were obtained for each participant and used to ensure that there were no outliers. Adult participants were recruited from the Institute of Cognitive Neuroscience, London, and from the Isle of Wight, UK. Adult participants were given information sheets giving brief details about the study and asking for their participation. Informed consent sheets were completed prior to testing.

3.4.2 Design

A novel computerised task was designed in which short scenarios were presented on a computer screen. Participants were asked to read the scenario and, once they had understood it, to press the space bar. This elicited the presentation of a question and three multiple choice answers below the scenario. The scenario remained on the screen to avoid participants having to rely on memory. Participants were asked to select a correct response to the question by using three highlighted keys on the computer keyboard (A, S or D corresponding to the answer on the left, middle or right). The next scenario was presented following selection of an answer. Time taken to select a response (time from when the question and three multiple choice answers appeared beneath the story, to when a response was selected) and accuracy were recorded as dependent measures. Time taken to read each story was also recorded, and used to eliminate outliers from the analysis.

There were with three conditions: a. *Mentalising:* the scenarios involved people and a mental state inference was required to select the correct response; b. *People-non mentalising:* the scenarios involved people but no mental state inference was required to select the correct response; c. *Physical*: the scenarios involved physical, natural events (no people) and an inference about the physical world was required to select the correct response. See Chapter 2 for details of task design with an illustration of task procedure, and Appendix B for examples of stories from each condition.

A previous study found an impaired ability to mentalise in adults with autism spectrum disorder (ASD – see Chapter 2). This impairment is consistent with impaired mentalising in ASD (Baron-Cohen et al., 1985; Happé, 1994), and the current task was therefore considered to be a useful measure of the ability to mentalise.

3.4.3 Analysis

Mean error rate in each puberty group was calculated for each condition (out of a maximum of 10 errors per condition). Median response time was calculated for each participant for each condition. To investigate the effect of puberty on performance in each condition, differences across condition and puberty for error rate, and response time, was analysed using an ANOVA with between-subjects factors of *Puberty* (pre-, mid-, post-, and adult) and *gender* (male, female), and within-subjects factor of *Condition* (Mentalising, People non-mentalising, Physical). Post-hoc simple effects analyses were used to investigate any second- or third- order interactions. To test for the pattern of any change in accuracy or response time across puberty, polynomial contrasts (linear or quadratic) were performed, excluding adult data. These contrasts assess the number of times a change occurs in the pattern of performance. If performance only follows one direction (e.g. increases over puberty) a significant linear pattern may be found. In contrast, if there is a change in the direction of performance, as in the inverted U trajectory, a significant quadratic pattern may be found.

3.5 Results

Median reading times were used to remove seven outliers (participants who had +/- 5 standard deviations from the mean reading time in each condition) who were omitted from the analysis. There were no outliers based on BPVS score.

3.5.1 Error Rate

Mean error rates in each condition across puberty are presented in Figure 3.1. ANOVA revealed a significant main effect of condition ($F_{(2,302)}=10.837$, $p<.0001$), gender ($F_{(1,151)}=6.132$, $p<.05$) and puberty ($F_{(3,151)}=5.045$, $p<.005$). There was a significant interaction between condition and puberty ($F_{(6,302)}=2.441$, $p<.05$).

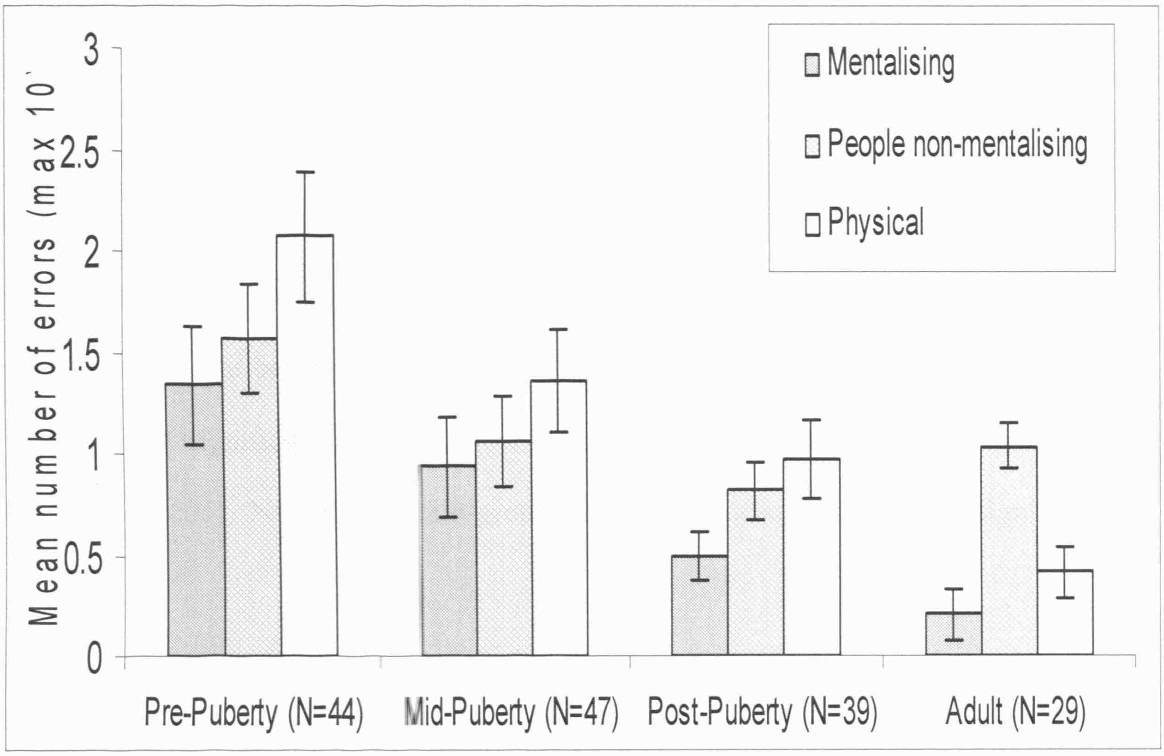

Figure 3.1: Mean error rate for each condition, for each group. Maximum possible error rate was 10.

3.5.1.1 Between-Group Comparisons

Post-hoc between-subjects simple effects analyses revealed that the pre-puberty group demonstrated significantly more errors than post-puberty and adult groups (both $p<.05$) in the mentalising condition ($p<.05$) and in the physical condition ($p<.0001$). The mid-puberty group demonstrated significantly greater errors than the adult group in the mentalising condition ($p<.05$). In the people non-mentalising condition, the pre-puberty group demonstrated significantly more errors than the post-puberty group ($p<.05$). In the physical condition, the mid-puberty group demonstrated significantly more errors than the adult group ($p<.05$). No other between-group differences were found to be significant ($p>.05$).

3.5.1.2 Within-Group Comparisons

The pre-puberty group demonstrated significantly more errors in the people non-physical ($p<.05$) and physical ($p<.001$) conditions than in the mentalising condition. The mid- and post-puberty groups demonstrated significantly more errors in the physical than mentalising condition ($p<.05$). The adult group demonstrated significantly more errors in the people non-mentalising condition than the mentalising condition ($p<.001$), and significantly more errors in the people non-mentalising than physical condition ($p<.05$). No other within-group differences were found to be significant ($p>.05$).

3.5.1.3 Development of mentalising across adolescence

Performance on the mentalising, people non-mentalising, and physical, conditions across the three puberty groups (excluding adults) showed a significantly linear pattern of improvement (all $p<.05$). Contrasts coding for a quadratic pattern of development did not significantly describe the data ($p<.05$). These results suggest that there was an improvement (decreased errors) between pre- and post-puberty, with no significant decrement in performance at mid-puberty.

3.5.1.4 Gender comparison

Overall, female participants demonstrated significantly lower error rates than male participants in mentalising ($t_{(157)}=-2.382$, $p<.05$), people non-mentalising ($t_{(157)}=-2.515$, $p<.05$), and physical ($t_{(157)}=-2.498$, $p<.05$) conditions.

It should be noted that high (verging on ceiling) levels of accuracy were obtained on this task, particularly in older participant groups (post-puberty, and adult). This could have affected results, and response time may be a more sensitive measure of performance than error rate.

3.5.2 Response Time

Mean response times of each puberty group in the three conditions are presented in Figure 3.2. ANOVA revealed a significant main effect of gender ($F_{(1,151)}$=7.786, p<.05) and puberty ($F_{(3,151)}$=14.372, p<.001). No other significant main effects or interactions were found (p>.05).

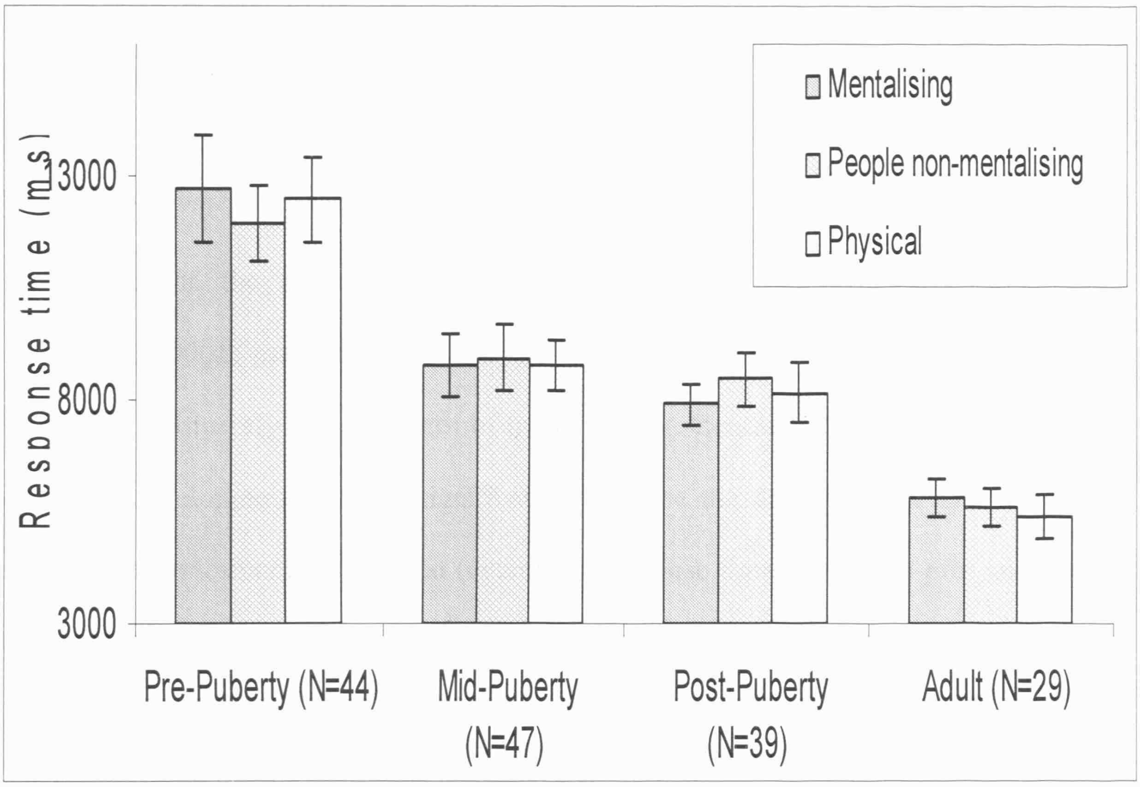

Figure 3.2: Mean response time in ms for each group in the three conditions of the mentalising task.

3.5.2.1 Between-group Comparisons

Post-hoc between subjects simple effects analyses revealed that in all three conditions, the pre-puberty group demonstrated significantly longer response times than the other groups (all $p<.001$ except between pre- and mid-puberty in people non-mentalising which was $p<.005$). The mid-puberty group demonstrated significantly longer response times than adults in the mentalising ($p<.05$), people non-mentalising ($p<.005$), and physical ($p\leq.001$), conditions. The post-puberty group demonstrated significantly longer response times than the adults in the physical and people non-mentalising ($p<.05$) conditions. No other significant differences were found ($p>.05$).

3.5.2.2 Within-group comparisons

No within-group simple effects were found to be significant.

3.5.2.3 Development of mentalising across adolescence

Performance on the mentalising ($p<.0001$), people non-mentalising ($p<.005$), and physical ($p<.0001$) conditions across the three puberty groups (excluding adults) showed a significantly linear pattern of improvement. Contrasts coding for a quadratic pattern of development did not significantly describe the data ($p<.05$). These results suggest that performance improved (decreased response times) between pre- and post-puberty, with no significant decrement at mid-puberty.

3.5.2.4 Gender comparison

Overall, female participants demonstrated significantly faster response times than male participants in mentalising ($t_{(157)}=-2.820$, $p<.05$), people non-mentalising ($t_{(157)}=-2.371$, $p<.05$) and physical ($t_{(157)}=-2.784$, $p<.05$), conditions.

3.6 Discussion

This study aimed to investigate the effect of puberty on the ability to infer other people's mental states (mentalising). The developmental trajectory of performance in three conditions (mentalising, people-non-mentalising, physical) was assessed using a computerised task. The task involved reading short stories and selecting multiple choice answers to a question about the relationship between events presented in the scenarios. It was predicted that, due to the protracted development of part of the neural network associated with mentalising, changes in performance on the mentalising condition relative to control conditions may occur during adolescence. In addition, it was predicted that the direction of development of mentalising would either be linear consistent with WM increases in the frontal and temporal cortices during adolescence (e.g. Paus et al., 1999), or an inverted U shape consistent with a non-linear trajectory of GM change observed in these regions during this time (e.g. Giedd et al., 1999). However, no specific change in mentalising performance during this time was found. While the current data indicated a significant linear improvement of mentalising during adolescence both in accuracy (decreased error rate) and response time, this pattern of development did not distinguish mentalising from the two control tasks.

The condition by puberty interaction found in the error rate data was driven by adults demonstrating significantly more errors in the people non-mentalising condition relative to the physical condition, compared with the other three puberty groups. The physical condition consists of stories based on natural, scientific-type events. A possible reason for significantly decreased error rate demonstrated by adults in this condition relative to the other control condition may be because the majority of adults were sourced from scientific backgrounds. This may have given them an advantage on the physical condition, and future research should control for this possibility.

Due to finding significantly longer response times in the mentalising condition relative to controls in individuals with autism spectrum disorder (ASD) (see Chapter 2) this result was unlikely to be due to an ineffective measure of the ability to mentalise, as ASD is a disorder characterised by impaired social cognition (see Frith & Frith, 2003 for a review). In addition, the result obtained with adults in Chapter 2 was found with a considerably smaller sample size than in the present study. However, in contrast to ASD, which is characterised by impaired social cognition, only *subtle* changes in the ability to mentalise during adolescence were predicted. It may therefore be that this task, while a valid methodology to study mentalising in clinical groups, is not sensitive enough to detect change in the ability to mentalise during typical adolescence.

3.6.1 Overall improvement may be associated with age-related cognitive development

In contrast to the prediction of a specific change in mentalising during adolescence, progressive linear improvement in response time in all three conditions over puberty was found. This improvement could be due to a number of factors including improved attention, memory, concentration, or motor coordination. First, all three conditions of the mentalising task involved EF such as attention, working memory, and decision making. Therefore improved performance across all conditions may reflect age-related improvement in EF, as documented in a number of studies (Anderson, 2001; Luna et al., 2001; Tamm et al, 2001). For example, the ability to attend to task material (selective attention) and hold this information in mind ('working memory'; Baddeley, 1986) improves with age (e.g. Anderson, 2001; Kwon et al., 2002). This may have resulted in the progressively faster response times seen across all three conditions with age in the current study. Second, the development of improved motor coordination could have affected the speed of response given by participants of different puberty groups. The pre-puberty group may have taken more time to coordinate a behavioural response than older puberty groups. Third, improved performance across all conditions from pre-puberty to adulthood may have been due to older participants using more effective response strategies. Younger participants might have felt less certain about the correct response, and/or engaged in more time-consuming checking behaviour by referring back to the story, compared with older participants. Fourth, older subjects may have paid more attention or concentrated harder whilst performing the task compared to younger children. This may have resulted in more efficient response selection, and therefore the decreased response times, demonstrated across puberty groups.

3.6.2 Female superiority on the novel task

While no specific female advantage for mentalising was found, the results of the current study indicated that females demonstrated significantly lower error rates and response times than males in each condition. This result is consistent with research indicating the existence of a female bias for language skills (Maccoby & Jacklin, 1974; Kimura, 1999), which is apparent from childhood, becomes more established in adolescence, and remains stable into adulthood (Parsons et al., 2005). This could have affected performance on the current language-based computer task, and may have resulted in the faster response times and lower error rates demonstrated by females compared to males. Research finding females outperform males in all major subjects through primary to high school, perhaps as a result of being more self-disciplined (Duckworth & Seligman, 2006), suggest that factors such as greater levels of concentration or motivation in females relative to males could have contributed to performance differences found on this task.

3.7 Future directions

Further research is required to investigate gender differences found in the current study. Systematic differences in speed or timing of pubertal development exist between males and females (Grumbach & Styne, 1998). For example, boys typically begin pubertal development one to two years later than girls (Tanner, 1962), with total cerebral volume peaking at an earlier age for females (11.5 years) compared to males (14.5 years) (Giedd et al, 1999). While participants were allocated to puberty groups as accurately as possible through the use of a self-report developmental questionnaire, the use of more reliable methods such as examination by a physician to determine Tanner stages of development (Tanner, 1962) would be advantageous. In addition to allowing more accurate categorisation of participants to puberty groups, such methods would also enable more reliable matching between male and female puberty stages.

Future research investigating the development of mentalising in adolescence may benefit from the use of more complex material, which is less susceptible to high levels of accuracy. For example, more difficult versions of mentalising tasks using non-verbal stimuli such as cartoons (e.g. Gallagher et al., 2001; Brunet et al., 2000) or animated shapes (Castelli et al., 2000) could be used. See section 1.1.2 of Introduction for full description of these paradigms. In addition, the detection of subtle changes in the ability to mentalise during adolescence may require more implicit measures than the stories used in the current study. Imaging studies using competitive game paradigms, where the explicit inference of another persons mental state is not required, have found greater activation of the mentalising network when participants believe that they are playing against a human opponent relative to a machine (e.g. Gallagher et al., 2002; McCabe et al., 2001; Rilling et al., 2004). For example, Gallagher et al. (2002) found increased activation of the mPFC during the trials in which participants believed they were competing against a human opponent relative to a computer, indicating that this region is activated by the mere belief of another person being present (see section 1.1.2 of Introduction for full details). Data obtained from these competitive game paradigms also indicate differences in the level of activation of the mentalising network during tasks involving implicit attribution of mental states to other people and those that involve mentalising in response to stimuli presented on a computer. The computer based task used in the current study required *explicit* inferences of mental states to be made. It may be that the mentalising network is more engaged during implicit mentalising tasks, and these paradigms may therefore be an interesting avenue for future research investigating this ability during adolescence.

Such research also emphasises the influence that real-life interactions (even imagined ones) can have on areas of the brain associated with mentalising. A limitation of 'laboratory' based tasks such as the one used in the current study is that they offer a rather contrived environment. Inferring the mental states of characters in stories during performance of a computer task is very different from the spontaneous mentalising that happens during real life social interactions. More ecologically valid mentalising tasks, such as those developed by Apperly et al. (2006) whereby the ability to understand the mental states of other people is assessed during visual displays of social interactions involving other people, may therefore be of use. This paradigm incorporates the complexity of the social environment; involving aspects of interaction commonly used every day to decipher the intentions of others, such as eye gaze, body posture, etc. The use of such tasks with adolescents, perhaps in the school environment or at home, would be of interest for future research.

Apperly et al. (2006) also found that adult participant's demonstrated longer response times to unexpected questions requiring mental state attributions, relative to when participants were instructed to think about mental states prior to interacting. Again, this illustrates the influence that explicit requirements to mentalise may have on performance. The difference between mentalising during 'natural' (i.e. no external influence) and 'task-directed' (i.e. asked to track the mental states of others) social interaction suggests that there may be a top-down influence of executive function on the ability to mentalise. Keysar et al. (2003) presented adults with a scenario in which they were asked to move objects around a grid on a table, as directed by another person (the 'director'). Prior to starting, participants were asked to hide an object in a bag, so that the director could not know the identity of this hidden object. However, occasionally the description of an object on the table closely matched the description of the hidden object. During these trials, participants often responded as if the director was referring to the hidden object, despite knowing that this was impossible as the director had not seen the object being hidden in the bag. Keysar et al. (2003) suggest that this shows dissociation between the ability to separate personal beliefs from the beliefs of other people, and the use of this ability when interpreting the actions of other people.

The role played by EFs such as response inhibition and working memory in these mentalising tasks is unclear. It may be that the ability to mentalise (i.e. knowing what another person knows) while keeping contradictory personal knowledge separate (i.e. knowing what you know) 'online' places limitations on working memory, or on the ability to inhibit prepotent responses. This requires future research. Again, the use of more ecologically valid methodology such as that of Keysar et al. (2003) would be of use in research with adolescents. Investigation of the potential role EFs play in inhibiting inappropriate responses during social interaction over the course of childhood and adolescence could have important implications for education and social policy regarding behavioural management during this time.

Finally, the employment of imaging techniques in which the neural substrates of mentalising during adolescence is investigated is also vital for uncovering the possible differences in neural strategy used for this social ability during adolescence.

3.8 Summary

This study investigated the development of mentalising during adolescence. It was predicted that a subtle change in this ability, relative to matched non-mentalising tasks would occur during puberty, due to continued maturation of frontal and temporal brain regions associated with mentalising, namely the PFC and STS, during this time (e.g. Giedd et al., 1999). The ability to mentalise was investigated using a novel computer task, which was completed by a large group of participants aged eight to 80 years old. Participants were allocated to puberty groups, and their performance during three conditions (one requiring mentalising, the other two non-mentalising controls) was compared. Contrary to the hypothesis, a difference in performance on the mentalising condition relative to control conditions across puberty was not found. In contrast, progressive linear improvement in all three conditions of the task was demonstrated. Gender differences in performance were found. Overall, females demonstrated significantly lower error rates, and faster response times, compared to males in all three conditions. This may have been due to a female bias in language skills (e.g. Parsons et al., 2005), and future research is required to further investigate these gender differences. More refined techniques, perhaps using naturalistic methodologies, would enable more sensitive investigation of mentalising during adolescence.

To further investigate development of mentalising during adolescence, an adapted version of Baron-Cohen et al.'s (2001b) 'reading the mind from the eyes' task was employed. This study is described in the next chapter.

Chapter 4

DEVELOPMENT OF MENTALISING DURING ADOLESCENCE USING THE 'READING THE MIND IN THE EYES' TASK

4.1 Recognition of intention from eye gaze during childhood

From birth, human infants show a preferential attraction to pictures of human face-like patterns compared to non face-like patterns (Umilta et al., 1996). This special interest in human faces continues to develop throughout the first year of life, whereby an increasing tendency to follow the eye gaze of other people is demonstrated (Scaife & Bruner, 1975). However, the eyes are only successfully used as a means of gaining information about the intentions of other people around the age of four years (Doherty & Anderson, 1999). This is also the age at which children pass mentalising tasks, which require an ability to understand the mental states of other people (Wimmer & Perner, 1983; Perner & Wimmer, 1985). Understanding the mental states of other people is known as 'Theory of Mind' (Premack & Woodruff, 1978), or mentalising (Frith & Frith, 2003). It has been suggested that attending to other people's eye gaze is important for this ability (Baron-Cohen et al., 1997a;b; Blakemore & Frith, 2003).

Research indicates that the ability to infer information about other people's mental states from attending to eye gaze improves over the course of childhood (Baron-Cohen et al., 2001b). Baron-Cohen et al. (2001b) presented children aged six to 12 years with a 'reading the mind from the eyes' task for children. This task involved the presentation of 28 pictures of actors' eyes on a computer screen, with four multiple choice intentions or emotions that might be shown in the eyes (e.g. worried, distracted, joking). For each item, participants were required to select the intention that they felt was being portrayed in the eyes. The results indicated a progressive improvement in the ability to identify correctly the emotion or intention between the ages of six and 12 years on this task.

4.2 Neural correlates of inferring intention from eye gaze in adults

Imaging research with adults has indicated that in both mentalising (Frith & Frith, 2003; Castelli et al, 2002) and eye gaze (Baron-Cohen et al., 1999c; Calder et al., 2002; Hooker et al., 2003) tasks, the medial prefrontal cortex (mPFC) and regions of the temporal lobes such as the superior temporal sulcus (STS) are activated. For example, Calder et al. (2002) presented nine female adults with photographs of people's faces, which varied in terms of the direction of eye gaze shown in the face (either direct, averted, down, or eyes closed). The results indicated that medial frontal regions, associated with mentalising tasks, were more engaged by photographs of people with direct and averted gaze than with down or no gaze. Similarly, Baron-Cohen et al. (1999c) presented the adult version of the reading the mind from the eyes task to a group of six adults and found significant activation of the amygdala, the left dorsolateral PFC, the left medial frontal cortex, and bilateral temporo-parietal regions, including middle and superior temporal gyri, during inference of intention and emotion to the stimuli relative to making a judgment about gender (non-mentalising condition). Research by Hooker et al. (2003) found selective activation of the STS for extracting directional information from eye gaze relative to an arrow, or to eye gaze without any relevant directional information. Such research emphasises the role played by the mPFC and STS in obtaining information from eye gaze.

The PFC and STS are among regions of the human brain that show protracted development into adolescence (Giedd et al., 1999; Paus et al., 1999; Sowell et al., 1999). Linear increases in white matter (WM) density and nonlinear changes in grey matter (GM) density have been found to occur in these areas over the course of adolescence (Giedd et al., 1999; Paus et al., 1999; Sowell et al., 1999). These changes are consistent with human post mortem studies showing evidence of continued myelination (Yakovlev & Lecours, 1967) and synaptic reorganisation (Huttenlocher, 1979) in the frontal cortex (see section 1.5 of Introduction for further description of these processes). Both maturational events have been posited to speed information processing, as myelinated fibres transmit impulses up to 100 times faster than unmyelinated fibres, and synaptic reorganisation serves to 'fine tune' neuronal connections into frequently-used networks (Blakemore & Choudhury, 2006).

4.3 Investigating the recognition of intention from eye gaze during adolescence

The impact of cortical development on social cognition, and the direction of any consequential change, is largely unknown. However, research finding development of other cognitive abilities associated with the PFC, such as executive function (EF) (e.g. Anderson et al., 2001; Luna et al., 2001), suggests that further development in social cognition (due to the association with the PFC) may also occur. For example, Anderson et al. (2001) found linear improvement on a variety of EF tasks up to age 17. However, nonlinear development of abilities pertaining to EF (McGivern et al., 2002) and face recognition (Carey et al., 1980; Diamond et al., 1983) has also been found. For example, Carey et al. (1980) presented 160 female participants between the ages of six to 16 years with a face-encoding task. The results indicated that while performance improved steadily between the ages of six to 10, the ability to encode faces remained constant or even declined for several years (around the onset of puberty), improving again at age 16 (Carey et al., 1980). These results are consistent with a later study by Diamond et al. (1984), whereby pubescent female participants demonstrated less efficient face encoding than pre- or post- pubescent female participants, regardless of age. Mixed evidence as to the developmental trajectory of skills associated with the PFC during adolescence has therefore been found.

The present study aimed to investigate whether any changes in the ability to infer intention and emotion from the eye gaze of others occurs during adolescence. A questionnaire version of Baron-Cohen et al.'s (2001b) computerised reading the mind through the eyes task (child's version) was developed to assess performance changes across puberty. It was hypothesised that changes in performance on the reading the mind in the eyes task would occur as a function of puberty. Puberty, rather than chronological age, was used due to the continued cortical maturation being a result of hormonal changes rather than simply a result of increasing age (e.g. Romeo, 2003; Wetzel, 1941; Krogman, 1950).

Two possible patterns of change were predicted. The first possibility is that there would be a linear improvement in the ability to infer mental states from eye gaze across puberty. This would be consistent with the linear WM development in the frontal and temporal cortices during this time, and studies showing linear improvement in abilities associated with the frontal cortex such as EF (e.g. Anderson et al., 2001; Luna et al., 2001). Alternatively, there may be an inverted U shaped pattern of performance, consistent with GM change in the frontal cortex and a number of studies finding non-linear development (McGivern et al., 2002; Carey et al., 1980; Diamond et al., 1983), during adolescence. For example, a decrement in performance may be found in the mid puberty group relative to pre- and post- puberty groups, in line with the second wave of proliferation of synapses in the frontal cortex around puberty onset.

4.4 Method

4.4.1 Participants

62 participants (14 male) aged 10.05 to 17.08 years took part in the present study. They were divided into three groups: pre-puberty (*n* = 10 (6 male), mean age 12.04 ± 0.37, range 10.05-14.02 years); mid-puberty (*n* = 26 (6 male), mean age 13.01 ± 0.23, range 10.05-15.04 years); and post-puberty (*n* = 26 (2 male), mean age 14.86 ± 0.19, range 13.02-17.8 years); based on a physical development questionnaire (see Appendix A) adapted from Carskadon & Acebo (1993).

Participants were recruited from schools in Birmingham and on the Isle of Wight, through letters detailing the study and asked for their participation. These letters were sent to the schools and handed to the pupils during registration. The study was approved by the local ethics committee, and both parental and participant consent was obtained prior to completion of the task. The British Picture Vocabulary Scale (BPVS; Dunn et al., 1997) was carried out with each participant individually at school. These data were used to ensure that there were no outliers (participants who had +/- 5 standard deviations from the mean standardised score) based on verbal ability.

4.4.2 Design

A self-report questionnaire was developed based on the child's version of the 'reading the mind from the eyes' computer task of Baron-Cohen et al. (2001b), sourced from the Autism Research Centre, Cambridge. The questionnaire consisted of a total of 28 photographs of pictures of actors' eyes expressing different intentions and emotions. Due to unforeseen circumstances, 31 children (3 in pre-puberty, 16 in mid-puberty, 12 in post-puberty) were administered half of the questionnaire (14 items). The other 31 children completed the entire questionnaire (28 items). An example, with the correct response ('thinking about something') selected, is presented in Figure 4.1.

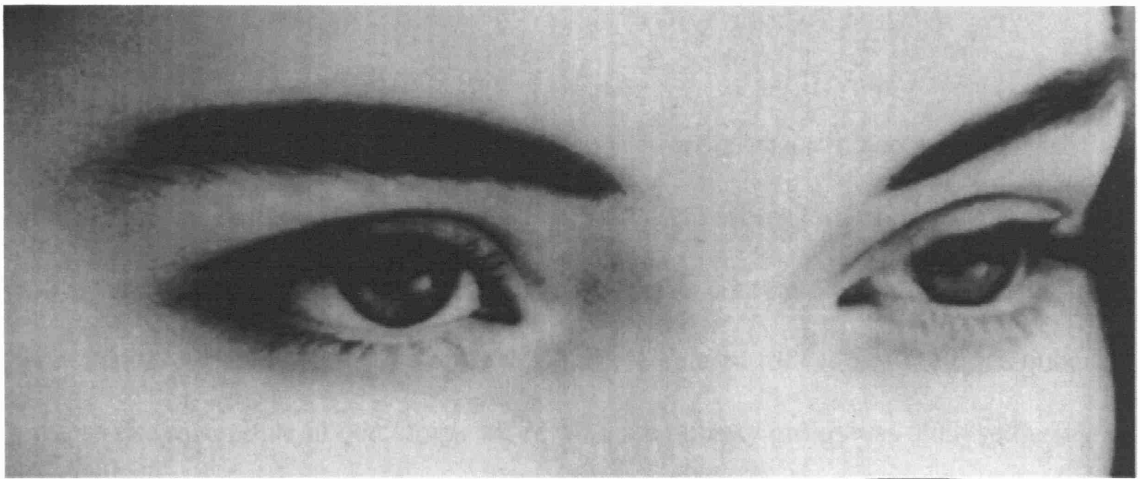

Figure 4.1: Example of one of the 28 items from the 'reading the mind in the eyes' task, child's version, developed from Baron-Cohen et al. (2001b). The correct answer for this item is 'thinking about something'.

Questionnaires were posted to participants, who completed them at home. Participants were asked to complete the questionnaires alone. For each item, participants were required to decide which intention or emotion was being expressed by selecting one out of four possible multiple choice answers. Responses were made by placing a circle around the chosen answer. As in the study by Baron-Cohen et al. (2001b), a score of nine or more out of 28 items was taken to be significantly above chance (binomial test, $p<.05$; from Baron-Cohen et al., 2001b). For the 14 item test, a score of seven was calculated (binomial test, $p<.05$). Overall, eight female participants failed to score above chance (one participant from the pre-puberty group, three from mid-puberty, and four from post-puberty, groups).

4.4.3 Analysis

For each individual, items were marked as correct or incorrect in accordance with the criteria used by Baron-Cohen et al. (2001b). Individual scores, out of a maximum of 14 or 28 depending on which questionnaire participants completed, were converted into percentages. A mean percentage score was then calculated for each of the three puberty groups. The difference in percentage score for each puberty group was analysed using a one way ANOVA with *Puberty* (pre-, mid-, post-, puberty) as a between-subjects variable. Due to small sample sizes, particularly in the pre-pubescent group, gender was not included as a variable in the analysis. To test for the direction of any change in performance across puberty, polynomial contrasts (linear or quadratic; see Chapter 3 for description) were performed.

4.5 Results

There were no outliers based on scores from the BPVS. The mean percentage correct performance across puberty is presented in Figure 4.2. A one-way between subjects ANOVA revealed no significant effect of puberty on performance ($F(2,59)=2.066$, $p>.05$).

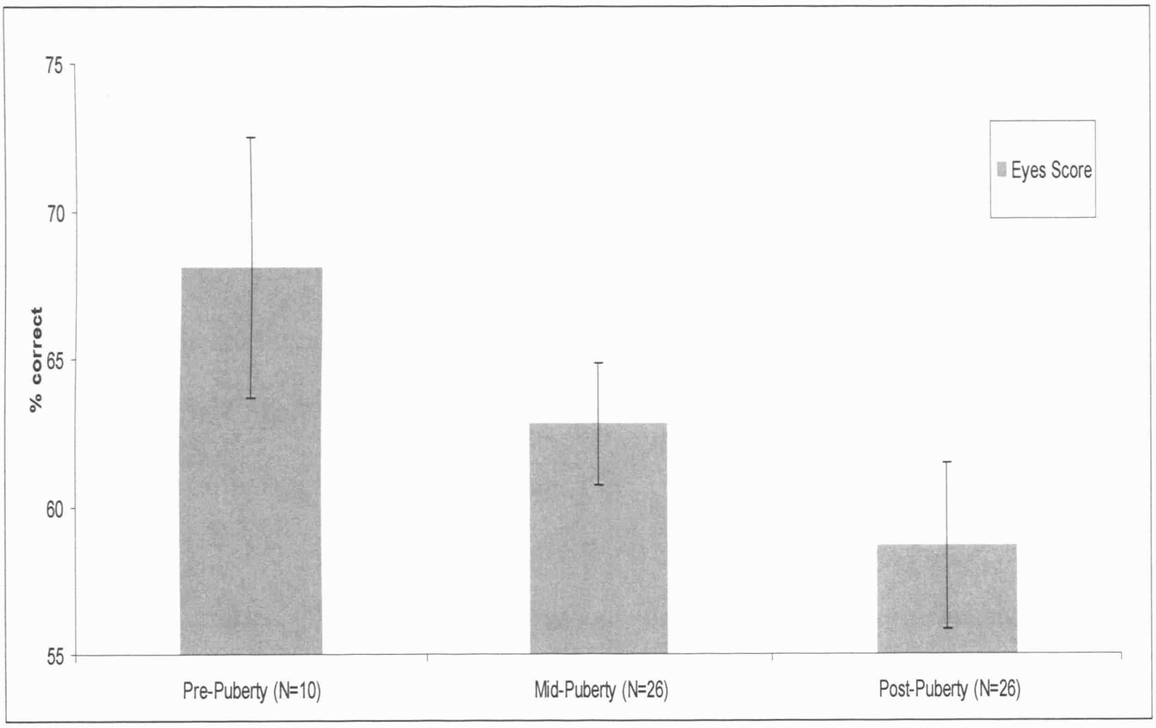

Figure 4.2: Mean percentage correct on reading the mind from the eyes task across puberty.

4.5.1 Development of recognition of intention from eye gaze across adolescence

Scores across the three puberty groups showed a near significant linear decline in performance (decreased error rates) ($p=.052$). Second-order polynomial contrast (quadratic) did not significantly describe the data ($p<.05$).

4.6 Discussion

The aim of the current study was to investigate whether any changes in performance on a questionnaire task developed from Baron-Cohen et al.'s (2001b) 'reading the mind from the eyes' test occurred during adolescence. It was hypothesised that the protracted development of neural regions associated with mentalising and eye gaze such as the PFC and STS (Calder et al., 2002; Hooker et al., 2003) into adolescence (Giedd et al., 1999; Paus et al., 1999; Sowell et al., 1999) may affect performance during this time. However, no significant differences in accuracy of identifying intention and emotion from eye gaze were found between puberty groups in the current study. Despite its preliminary nature, the data suggests comparable ability over adolescence on this task, consistent with the stability of performance in late childhood (age eight to 12 years) found by Baron-Cohen et al. (2001b). These preliminary findings suggest that this stability of performance may continue to age 17.

There are a number of other possible reasons for comparable performance across puberty. First, there may be an inherent difficulty in inferring accurate mental state attributions on the basis of static pictures of the eye region of others, as used in this and previous 'eyes' tasks. Baron-Cohen et al. (2001b) found that the oldest age group (10-12 years) in their study demonstrated around 73% accuracy on the original computerised version. This is comparable to adult performances, at which an average of 76% accuracy has been found using the adult version of the computer task (Baron-Cohen et al., 2001a). In the current study, the pre-puberty group (aged around 12 years) demonstrated similar (71%) levels of accuracy as that of the oldest participants and adults in the studies by Baron-Cohen et al. (2001a;b). This ability therefore appears to not show any improvement, shown by comparable levels of performance between children and adults in the Baron-Cohen et al. (2001a;b) studies and consistent with the current findings, past late childhood. In addition, accuracy was not improved by presenting the stimuli in questionnaire format compared with results obtained using the computerised version used by Baron-Cohen et al. (2001a;b).

Second, the effect on social cognition of protracted brain development during adolescence may be too subtle to be detected using the current method. It is clear that adolescence is not a period of complete social impairment. More sensitive behavioural measures, such as the inclusion of response time as used by McGivern et al. (2002), may be useful to investigate further the impact of continued development of social cognition during this time. Subtle differences in the speed of processing intention from eye gaze during adolescence may be detected using this method. Second, the importance of making eye contact with others is widely acknowledged (Farroni, et al. 2004). This ability may therefore be too ecologically significant to be affected by any subtle change in social cognition that may occur due to protracted cortical development during adolescence. For example, the capacity to infer that there may be a risk of danger from the eye gaze of other people may give this ability a certain level of protection against change due to maturational events in the cortex.

4.6.1 Possible decline in performance during adolescence

While no significant differences in performance were found between puberty groups on this task, polynomial contrasts investigating the pattern of performance across puberty indicated a near-significant linear decline in accuracy during this time, such that performance declined from 71% accuracy in pre-, to 65% in mid-, and 61% in post-puberty. As a decline in performance was not found using the computerised version of the task with children aged from six to 12 years (Baron-Cohen et al., 2001b), this result could have been due to the methodology used in the present study. For example, questionnaires were completed at home, without the supervision and direction of an investigator. The data could therefore have been influenced by extraneous variables such as attention and motivation, which may have been lower in mid- and post-pubescent participants.

Alternatively, it may be that maturational events occurring in the brain during this time had an increasingly inhibitory effect on the ability to recognise intention from eye gaze. Research has indicated that a more gradual trajectory of GM change occurs in regions of the temporal cortex, such as the STS, than in the frontal lobes over the course of development (e.g. Giedd et al., 1999; Toga et al., 2006). Rather than reaching a maximal amount around the age of puberty onset as in the frontal cortex, GM density in the temporal cortex peaks later, around the 16 years (Giedd et al., 1999). It could be that performance on this task was affected by this process, with gradual increases in GM density causing subtle detriments in accuracy that continued past mid-puberty (where previous research has found a puberty 'dip' on tasks associated with the frontal lobes, e.g. McGivern et al., 2002) and into post-adolescence. A group of more mature participants would therefore be required to assess performance past the age of maximal GM density (16 years+) in this region of the brain.

However, such theorising is merely speculative at this stage, and the results of the current study are preliminary. Due to a paucity of research investigating eye gaze during adolescence, future research is required to further investigate any potential change in this ability during this time.

4.7 Future Directions

Future research may benefit from the use of more sensitive measures to investigate the existence of any subtle changes in the ability to infer intention from eye gaze during adolescence. For example, reverting back to the original computerised version of the task (Baron-Cohen et al., 2001a;b) with the addition of software to record response time may serve as an additional and potentially more sensitive measure of processing the eye gaze of other people.

The development of more ecologically valid tasks is also an important consideration for future investigations. While the use of the eye region alone in the 'reading the mind from the eyes' tasks may demonstrate the importance of eye gaze on the ability to infer intention and emotion in children and adults, this may not be the only source of information used to infer intent during real life social interactions. The attribution of intention and emotion from static, monochrome pictures of actors' eyes, with a restricted number of possible responses (one of which is deemed to be the correct answer), and an unlimited time frame differs considerably from the dynamic process of inferring the internal states of others during every day interactions. Laboratory type eye gaze tasks, such as the current pen and paper task, may therefore involve different cognitive processes compared to those involved during real life interactions with others.

While acknowledging the importance of the eye region in mentalising, future research using more real to life research techniques is therefore advocated. For example, the attribution of intention and emotion from eye gaze during interactions with others rather than from photographs may lead to a more accurate understanding of the way in which children and adolescents use reference points such as eye gaze in every day situations.

An interesting paradigm has been developed by Garau et al. (2001), in which participants engage in dyadic conversations with humanoid avatars presented on a computer screen. Garau et al. (2001) compared participant ratings of quality of communication with an avatar that had 'informed' gaze, i.e. it appeared to respond in an appropriate manner to the participant during a conversation, relative to when the avatar displayed random (non responsive) gaze. Significantly higher levels of satisfaction with communication were reported for interactions with an avatar when it appeared to be responding with appropriate (informed) relative to random eye gaze (Garau et al., 2001), demonstrating the importance of reciprocal eye gaze during social interaction. The use of avatars with malleable eye gaze patterns could be an interesting method of investigating the ability to infer intention from eye gaze during adolescence.

Gender differences on the original computerised version of this task were not found in Baron-Cohen et al.'s (2001b) previous study with children aged six to 12 years. However, an earlier study with adults using an adult version of the same task found superior performance by females relative to males (Baron-Cohen et al., 2001a). This gender difference may be developmental, appearing over the course of adolescence. Further research is required to investigate the timing and trajectory of this difference.

The current study is limited by unequal distribution of males to females, and small sample size (particularly in the pre-puberty group) of the three groups. Future research including larger numbers of male participants, with equal male: female ratios in each puberty group and a more mature or adult participant group, would increase the validity of the methodology, enabling further investigation of the near-significant decline in performance found in this study, and allow for an investigation of gender differences.

4.8 Summary

This preliminary study aimed to investigate the ability to infer intention from the eye gaze of others. A questionnaire task was developed from Baron-Cohen et al. (2001b) reading the mind from the eyes task. The results showed no evidence that the ability to identify intentions and emotions from eye gaze improved between pre- and post-puberty. This is consistent with findings of Baron-Cohen et al. (2001b), and extends this from 12 up to 17 years. In contrast, accuracy showed a near-significant linear decline during this time. This may have been due to the use of a questionnaire version of the original task, which was completed at home without the supervision of an investigator. In addition, this study had small sample sizes and unequal distributions of male to female participants in puberty groups. Additional research is therefore required to further investigate the possibility of change in the ability to infer intention from eye gaze during adolescence.

The ability to infer the intentions and emotions of other people may be associated with empathy. Consistent with this, activation of regions including the PFC during tasks of empathy have been found (e.g. Farrow et al., 2001). While data from both adolescent studies have failed to find any significant change in the ability to mentalise during adolescence (Chapters 3 and 4), empathic understanding was investigated as a possible area in which change may be found during this time. The development of empathy during adolescence is the subject of the next chapter.

Chapter 5

DEVELOPMENT OF EMPATHY DURING ADOLESCENCE

5.1 Empathy during childhood

Empathy is the capacity to understand and respond to the unique affective experiences of another person (Decety & Jackson, 2006). Infants as young as 14 to 20 months demonstrate empathic responses such as emotional concern when viewing simulations of other people in distress (Zahn-Waxler et al., 1992; Spinrad & Stifler, 2006). Further empathic development occurs over childhood. For example, young children tend to emotionally respond to another person's experiences based on the event causing the emotion rather than the emotion itself (Rosenblum & Lewis, 2003). The ability to focus on and emotionally respond to the *subjective* experiences of others develops between ages five to 13 years (Strayer, 1993). Strayer (1993) presented 138 children aged five to 13 with two sets of vignettes depicting emotional scenes (e.g. a child feeling distressed after being disciplined by a parent). Participants watched each vignette and then described the main emotion that each vignette made them feel (e.g. sadness, happiness etc). The results indicated age-related improvement in the ability to understand the emotions of others, suggesting continued development in empathic understanding to age 13 (Strayer, 1993).

5.2 Neural correlates of empathy in adults

Imaging studies with adults have found increased activation of brain regions including the prefrontal cortex (PFC) during tasks of empathy (e.g. Farrow et al., 2001; Decety & Chaminade, 2003). Farrow et al. (2001) found significant activation of the left superior frontal gyrus, orbitofrontal gyrus, and precuneus, during empathy judgments relative to social reasoning judgments. Decety and Chaminade (2003) presented participants with a series of video clips in which actors described either neutral or sad stories. Relative to the neutral video clips, increased activation of the anterior superior frontal gyrus, inferior frontal gyrus, temporal pole, and amygdala, was found for the emotional video clips (Decety & Chaminade, 2003). These studies are consistent with a 'social brain' theory regarding the neural basis of empathy, in which the involvement of four main brain regions, namely the medial frontal and orbitofrontal cortices, the amygdala, and the superior temporal sulcus or STS, are postulated to be of importance for experiencing empathy toward others (Brothers, 1990). Data from lesion studies have indicated a reliance on frontal/executive functions for empathic perspective taking (Kirsch et al., 2006), and decreased empathy has been found in patients with damage to the frontal lobes (Grattan & Eslinger, 1992; Shamay-Tsoory et al., 2003). Such research emphasises the role played by frontal brain regions in empathy.

5.3 Investigation of empathy during adolescence

Recent structural imaging studies (Giedd et al., 1999; Paus et al., 1999; Sowell et al., 1999) have indicated continued development of brain regions associated with empathy such as the PFC, such that linear increases in white matter (WM) volume and non linear changes in grey matter (GM) volume occur over the course of adolescence and even into young adulthood (Reiss et al., 1996; Sowell et al., 1999; 2002). Specifically, an increase in GM density occurs during childhood that peaks around age 12 in the dorsal frontal and parietal lobes, and around age 16 in the temporal lobes, followed by a decline over the course of adolescence (Giedd et al, 1999; Sowell et al, 1999). In contrast, total WM density steadily increases over this age range (Giedd et al, 1999). WM and GM development are consistent with human post mortem studies showing continued axonal myelination (Yakovlev & Lecours, 1967) and synaptic reorganisation (Huttenlocher, 1979) respectively, in regions of the frontal cortex, in particular the PFC, during adolescence. See Introduction (section 1.5) for full description of these processes. The potential influence of myelination may be increased speed of processing, while synaptic reorganization may serve to 'fine tune' neuronal connections, in developing cortical regions during adolescence (Blakemore & Choudhury, review 2006). This may cause aspects of social cognition associated with the frontal and temporal cortices, such as empathy, to change during this time.

Despite the importance of empathic skills in social relationships during adolescence (Bandura et al, 2003), there is a paucity of research investigating how empathy develops during this time. Studies investigating the development of other abilities associated with the PFC, such as executive function (EF), have reported mixed results (see section 1.5.4 of Introduction for details). The existence of cognitive change associated with regions such as the PFC during this period suggests that subtle developments in empathy, also associated with the PFC, may also occur during adolescence. It was therefore hypothesised that a change in empathy would occur during adolescence consistent with development of frontal (e.g. PFC) and temporal (e.g. STS) brain regions, with two possible patterns of change. First, a linear increase in empathy may be found, due to linear increases in WM density in regions associated with social cognition and consistent with improvements in other abilities associated with the PFC such as EF during this time (e.g. Anderson et al., 2001). Alternatively, development might be non linear and follow an inverted U shaped pattern. For example, relative to pre-puberty, there might be a decrement in empathy at mid-puberty which is overcome in post-puberty. This would be consistent with the nonlinear pattern of GM change reflecting synaptic reorganisation in brain regions such as the PFC and studies finding nonlinear patterns of performance during adolescence (e.g. McGivern et al., 2002). As these maturational changes are specific to brain regions associated with empathy, it was predicted that during adolescence a greater change in empathising relative to the control condition (systemising) may occur.

A questionnaire was developed for use with children and adolescents based on the Empathising (EQ) and Systemising (SQ) quotients of Baron-Cohen et al. (2003). These questionnaires measure the tendency to understand people and relationships (EQ) and the tendency to understand processes and machines (SQ). Past research (e.g. Baron-Cohen et al., 2002; 2003) has found the EQ and SQ to be useful measures of empathising and systemising. For example, consistent with a female superiority in empathy, females consistently score higher on the EQ and lower on the SQ than males (Baron-Cohen et al., 2002; 2003; Baron-Cohen & Wheelwright, 2004).

The task consisted of a series of short (one sentence) statements describing various traits relating to high or low levels of empathising or systemising. Participants were required to rate each sentence indicating how strongly they disagreed or agreed with each item. It was presented to participants aged between 11 and 16 years, who were classified into three puberty groups (pre-, mid-, and post-, puberty). Puberty rather than chronological age was used as the independent measure, as maturational change is associated with physical development rather than age per se (e.g. Romeo, 2003; Wetzel, 1941; Krogman, 1950).

5.4 Method

5.4.1 Participants

65 female participants aged 11.11 to 16.02 years took part in the present study. They were divided into three groups: pre-puberty (*n* = 11, mean age 12.33±0.23, range 11.11-14.02 years), mid-puberty (*n* = 31, mean age 13.12 ± 0.16, range 12-15.06 years), and post-puberty (*n* = 23, mean age 14.87 ± 0.17, range 13.02-16.05) based on a standardised development questionnaire (see Appendix A) adapted from Carskadon & Acebo (1993). Participants were recruited from schools in South London and on the Isle of Wight and were of similar socio-economic background. These participants were recruited through letters distributed at school that detailed the study and asked for their participation. Both parental and participant consent was obtained before the study, which was approved by the local ethics committee. The British Picture Vocabulary Scale (BPVS; Dunn et al., 1997) was carried out with each school-aged participant individually at school. Standardised scores were obtained for each participant and used to ensure that there were no outliers (participants who had +/- 5 standard deviations from the mean standardised score) based on verbal ability.

5.4.2 Design

A self-report questionnaire was developed from the EQ and SQ of Baron-Cohen et al (2003), sourced from the Autism Research Centre, Cambridge. The EQ and SQ were combined to form one questionnaire. Items were adapted for use with children, and neutral control sentences were omitted to shorten length. The questionnaire consisted of two types of sentence: i. empathising, and ii. systemising. A total of 77 (39 empathising and 38 systemising) sentences were included. Examples of these two types of sentences are presented in Figure 5.1.

Empathising:

I find it easy to put myself in somebody else's shoes.

Strongly agree   Slightly agree   Slightly disagree   Strongly disagree

Systemising:

In maths, I am interested in the rules and patterns of numbers.

Strongly agree   Slightly agree   Slightly disagree   Strongly disagree

Figure 5.1: Example of an empathising and a systemising sentence.

Questionnaires were posted to the parents of participants and were administered at home. Participants were asked to complete the questionnaires alone. After reading each sentence, participants were asked to judge how similar they were to the sentence using a scale from 'strongly agree' to 'strongly disagree'.

5.4.3 Analysis

As in the original tasks (Baron-Cohen et al., 2003), approximately half of the empathising and systemising items were reverse scored and participants could score 2, 1 or 0 for their responses. These marks were summed for all of the empathising, and all of the systemising, sentences for each participant. There were 39 sentences relating to empathising, and 38 sentences relating to systemising. Therefore, there was a maximum score of 78 for empathising, and 76 for systemising. To enable comparison between empathising and systemising scores across groups, scores were converted to percentages (giving a percentage agreement "score"). Higher scores reflected stronger agreement with the sentences. An average empathising and systemising score was then calculated for each of the three puberty groups. Empathising and systemising scores for each puberty group was analysed using an ANOVA with a between-subjects factor of *Puberty* (pre-, mid-, post-) and a within-subjects factor of *Condition* (empathising, systemising). Simple effects analyses were used to investigate any interactions. Polynomial contrasts (linear/quadratic; see Chapter 3 for description) were used to investigate the pattern of performance in empathising and systemising across adolescence. As in the adult study (Baron-Cohen et al., 2003) a correlation analysis was also performed between overall empathising and systemising scores.

5.5 Results

There were no outliers according to BPVS results. Mean scores for empathising and systemising across puberty are shown in Figure 5.2. ANOVA revealed a significant main effect of condition ($F(1,62)=30.504$, $p<.0001$) and a significant interaction between condition and puberty ($F(2,62)=11.839$, $p<.0001$). The main effect of puberty was not significant ($F(2,62)=.536$, $p>.05$).

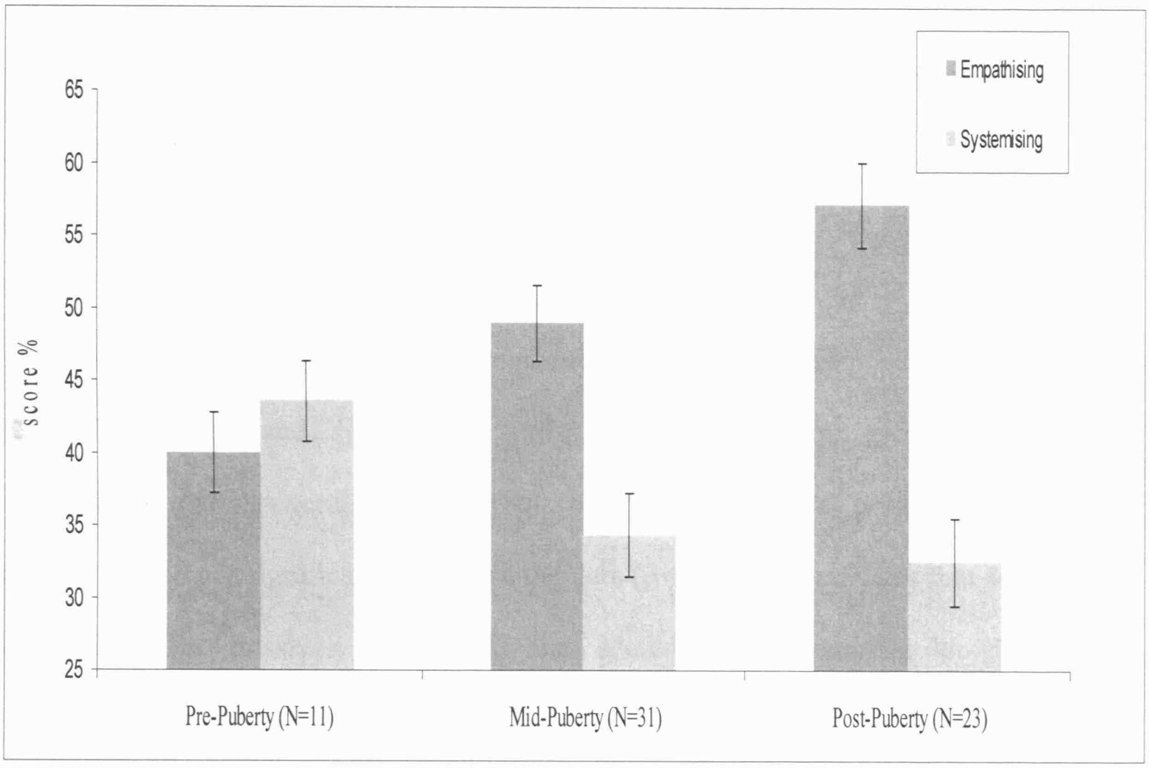

Figure 5.2: Mean scores for empathising and systemising across puberty.

5.5.1 Between-group comparison

Between subjects post-hoc simple effects analysis revealed that for empathising, the post-puberty group demonstrated significantly higher scores than the pre- ($p<.001$) and mid- ($p<.05$) puberty groups, and the mid-puberty group demonstrated significantly higher scores than the pre-puberty group ($p<.05$ one-tailed). For systemising, the pre-puberty group demonstrated significantly higher scores than the post-puberty ($p<.05$) group. No significant difference was found between the pre- and mid-, or mid-and post, puberty groups for systemising ($p>.05$).

5.5.2 Within-group comparison

Within subjects post-hoc simple effects analysis revealed significantly higher scores for empathising than systemising in the mid- and post- puberty groups ($p<.0001$), but not the pre-puberty group ($p>.05$).

5.5.3 Development of empathy and systemising across adolescence

Both empathising and systemising across the three puberty groups showed a significantly linear pattern of change (both $p<.05$). Second-order polynomial contrast (quadratic) did not significantly describe the data ($p<.05$). This indicates that scores for empathising progressively increased, and scores for systemising progressively decreased, across puberty.

5.5.4 Correlation between empathising and systemising in adolescence

No significant Pearson correlation between overall empathising and systemising scores was found in adolescence ($r=.231$, $p>.05$).

5.6 Discussion

This study investigated the development of empathy in adolescence, as indexed by a version of the EQ/SQ (Baron-Cohen et al, 2003) developed for use with children and adolescents. It was hypothesised that further developments in empathy may occur during adolescence due to imaging studies (e.g. Giedd et al, 1999; Sowell et al, 1999) finding extended development of regions of the frontal and temporal lobes associated with empathic understanding in adults (Brothers, 1990; Farrow et al., 2001) during this time. Consistent with this hypothesis, the results indicated a significant interaction between puberty and condition such that empathising increased and systemising decreased across puberty. Specifically, while participants rated themselves equally on the empathising and systemising measures at pre-puberty, higher levels of empathising and lower levels of systemising were reported in mid- and then post- puberty. These preliminary data suggest therefore that the propensity toward higher empathising than systemising occurred after the onset of puberty, during mid- to late-adolescence (around 13 to 15 years). In addition, finding greater levels of empathising relative to systemising between pre- and post- puberty indicates that this propensity increased over the course of adolescence.

5.6.1 Development of empathising and systemising during adolescence

While in opposite directions, linear change in both empathising and systemising was found during adolescence. Such linearity of empathising and systemising development is consistent with the linear progression of WM in areas of the brain associated with empathy, such as the PFC (Brothers, 1990; Farrow et al., 2001; Decety & Chaminade, 2003). Myelination (Huttenlocher, 1979) in these regions may cause increases in speed of processing information relating to social cognitive abilities such as empathy. Speculatively, this development may be one factor that enables deeper consideration and care toward the experiences of others, leading to changes in empathic understanding during this time. Increased empathy during adolescence is consistent with past research by Strayer (1993), extending the development of empathy from age 13 up to age 16.

There may also be environmental factors causing this developmental change. Increased empathising during adolescence may also be a response to more adult-like responsibilities and experiences placing greater demands on individual social cognitive abilities. Societal pressures to display high levels of empathy for others may become increasingly influential during this time. These demands may lead to greater levels of empathy being developed, or at least exhibited, over the course of adolescence as found in the current study.

Baron-Cohen et al. (2003) suggested that as empathising and systemising are separate processes, there should not be a 'necessary trade-off' in performance when responding to these two types of sentences. This is consistent with the lack of significant correlation ($r=.231$, $p>.05$) between empathising and systemising found in the current study. However, a significant negative correlation was found in adults on this task (Baron-Cohen et al., 2003). It may therefore be that this is not yet the case for children and adolescents, and a link between empathising and systemising may develop during later adolescence (after age 16) and adulthood. Future research is required to investigate whether this negative correlation is indeed developmental in nature.

5.7 Future Directions

While the current study provides interesting preliminary results indicating that development in empathising, and systemising, occurs during adolescence, further research is required to address a number of limitations of the current study. First, the use of a rating scale as the only means of measurement is not ideal. For example, despite anonymous completion of the task, the desire to create a 'good' impression as being individuals who are sensitive to the feelings of others may have affected responding. This may have been stronger in older than younger participants, perhaps due to a heightened awareness of social expectations with age. The development of behavioural studies employing experimental techniques, including more sensitive measures such as accuracy and response rate, may therefore enable a more objective assessment of change in empathic understanding during adolescence. One possibility could be to adapt classic tasks involving inferring the thoughts of other people, such as the strange story paradigm by Happé (1994) to assess empathy toward others during adolescence (see Fletcher et al's 1995 study in section 1.2.1 of Introduction for description of this paradigm). This task has the potential to present more complex, real life scenarios, and in addition may be computerised as in the novel task developed for the current thesis (Chapter 2 and 3) to record response time. Response time may present a more sensitive dependent measure of performance than the four-point Likert style responses used in the current task, and would enable additional information to be collected as to the nature of empathic development during adolescence.

Second, laboratory-type studies such as the current pen and paper questionnaire task have limited ecological validity. The relationship of responses made to the current questionnaire to real life empathic understanding and behaviour is unknown. Therefore, the development of more naturalistic behavioural tasks investigating the real-life empathic abilities of children and adolescents would be of benefit. For example, the inclusion of empathy tasks eliciting spontaneous demonstrations of empathic understanding and behaviour toward others could provide an additional source of data to the more controlled laboratory tasks investigating empathy. Third, due to its reliance on behavioural methodology, the current study cannot identify neural substrates of empathy and systemising during adolescence. Imaging studies are necessary to investigate cortical activation during tasks requiring empathy over the course of adolescence. This may also help disentangle the relative effects of continued brain development, environment, and brain-environment interactions, on empathy during adolescence.

Fourth, the inclusion of male participants is important for future investigations of empathy development in adolescence. Research has indicated consistent gender differences in performance on Baron-Cohen et al.'s (2003) original EQ/SQ questionnaires, such that females show higher scores on the EQ, and males on the SQ, in both normative and clinical adult samples. As the data obtained in the current study found differences across adolescence, the current task may be considered a useful measure of these constructs in children and adolescents. Employing the current task with a group of male participants aged 10/11 to 16/17 years may therefore enable investigation of possible gender differences in the developmental trajectory of empathy during adolescence. Finally, larger sample sizes are required to increase the validity of data obtained using the current methods.

5.8 Summary

This study aimed to investigate whether any changes in empathy occurred over adolescence. Research with adults has indicated that empathic understanding of other people is associated with frontal and temporal brain regions, including the PFC (e.g. Farrow et al, 2002). These regions show protracted development into adolescence (e.g.

Giedd et al., 1997; Paus et al., 1999). It was therefore hypothesised that empathy may show continued progression during this time. A questionnaire was developed using the 'empathising' and 'systemising' quotients of Baron-Cohen et al. (EQ and SQ; 2003) and employed with a group of female participants aged between 11 and 16 years. The task involved rating the strength of agreement with sentences depicting either empathising (associated with the EQ) or systemising (associated with the SQ) - type traits. The results indicated a significant interaction between condition (empathising, systemising) and puberty group (pre-, mid-, post-) such that a significant increase in agreement with empathising, and a significant decrease in agreement with systemising, occurred after the onset of puberty (in mid and post puberty). This is consistent with continued development of brain regions associated with empathy, such as the PFC, during adolescence. In addition, these changes were found to be linear, in line with linear increases in WM in brain regions such as the frontal cortex during this time. Further research is required to fully investigate the nature and implications of these findings.

Like empathy, the processing of emotion is also associated with the social brain network. Investigation into possible changes in emotion processing as a result of continued development of regions such as the PFC during adolescence are described in the next chapter.

Chapter 6

DEVELOPMENT OF BASIC EMOTION IN ADOLESCENCE

6.1 Basic emotion in childhood

Processing and understanding emotion is essential for social interaction (Lobaugh et al., 2006). It enables communication, monitoring, evaluation, and modification, of our own and others' emotional reactions, so that personal goals may be accomplished (Thompson, 1994). Research demonstrates that emotional responsivity is observed from a young age. For example, within the first three months of life infants begin to exhibit universal facial expressions associated with basic emotions such as happy and sad (Izard, 1971; Izard & Malatesta, 1987).

Ekman et al (1982) proposed that there are six basic emotions: happy, sad, anger, fear, disgust, and surprise, which can reliably be identified from facial stimuli (Kirouac & Dore, 1985) and are recognised and expressed across cultures (Ekman, 1972; 1999). Over the course of childhood, competence in expressing these basic emotions improves and becomes more complex. For example, as children develop, they learn how best to regulate their emotions in order to conform to the expected norms of society and culture (Gordon, 1989). Display rules, which are culturally defined and used to guide behaviour toward conforming to social norms, become increasingly used and understood by children aged three to four years (Gnepp & Hess, 1986). By this age children also begin to understand that a person's expressed emotion does not necessarily have to match their inner emotion (Harris, 1989). Around the age of 10 to 12 years, children develop an understanding of the ability to feel more than one basic emotion simultaneously ('mixed' emotion; see Harris, 1989; Harter, 1983; Larsen et al.,

2007) and appreciate that past events may influence current emotional state (Harris, 1989). The ability to integrate basic emotional information while simultaneously managing own behaviour ('emotional regulation'; Thompson, 1994), develops therefore over the course of childhood.

The ability to intentionally reproduce facial expressions of basic emotion improves between five and 14 years (Ekman et al., 1980), suggesting improvement of emotion understanding and control during this time. However, despite the overall improvement seen between these ages, Ekman et al. (1980) found performance stabilised from 10 to 14 years. Durand et al. (2007) found that the recognition of anger, fear, happy, sad, and disgust reach adult levels by the age of 11 (Durand et al., 2007). Therefore there is some evidence to suggest that basic emotion processing may be completed during late childhood. However, little empirical research has studied basic emotion processing past this age.

6.2 Emotional development in adolescence

Adolescence is a notoriously difficult period of emotional development. Increased feelings of distress (Freud, 1946; Gurian, 1996) and even changes of personal identity (Erikson, 1970) may arise during this time. Larson et al. (2002) examined change in adolescents' daily range of emotional states between early and late adolescence. The results indicated that the experience of greater levels of negative and lower positive extremes of emotion were highest between 10 to 14 years (Larson et al., 2002). In contrast, greater stability in relative levels of happiness was reported during late adolescence, between 14 and 18 years. While there is a paucity of research investigating basic emotion processing in adolescence, early adolescence may therefore represent a peak time of emotional change which is then followed by a slowing of change, or a stabilisation of emotion, after this time (Larson et al., 2002). In addition, a small number of behavioural studies have found a decline in performance at puberty on tasks involving basic emotion stimuli (Carey et al., 1980; Diamond et al., 1984; McGivern et al., 2002 see section 1.5.4 of Introduction). Such findings raise the possibility of further change occurring in basic emotional development during adolescence.

6.3 Neural correlates of basic emotion in adults

The perception of faces compared with objects has been found to activate the inferior occipital gyri, the lateral fusiform gyrus, and the superior temporal sulcus (STS) (see Haxby et al., 2000 for a review). Research investigating the neural correlates of basic emotion processing in adults has therefore compared brain activation to different types of basic emotional expressions (e.g. fear compared with anger), or basic relative to neutral facial expressions. This research has indicated that many brain regions are involved in basic emotion processing, including the occipito-temporal cortices, amygdala, orbitofrontal cortex, and right parietal cortices (see Adophs, 2002). Sprengelmeyer et al. (1998) investigated the neural correlates of perceiving facial expressions of basic emotions (disgust, fear, anger) relative to neutral facial expressions during a gender discrimination task. The results indicated significant activation of the left inferior frontal cortex for all three emotions relative to neutral facial expressions. Similarly, Kesler-West et al. (2001) found increased activation of frontal regions including the left inferior frontal gyrus during conscious processing of anger and fear relative to neutral facial expressions in participants aged 18 to 45 years. In addition, the medial frontal cortex was activated during viewing of angry and happy faces relative to neutral or scrambled faces (Kesler-West et al., 2001). Phillips et al. (1998b) presented adults with facial and vocal expressions of fear and disgust. Significant activation of the superior temporal gyrus was found during processing these basic emotional stimuli relative to control conditions (neutral facial expressions, and mildly happy vocal sounds). These studies indicate involvement of frontal and temporal lobes in basic emotion processing in adults.

6.4 Investigation of basic emotion in adolescence

The frontal and temporal cortices show protracted development into adolescence (Giedd et al., 1999; Paus et al., 1999; Sowell et al., 1999). Specifically, a progressive increase in white matter (WM) density has been found in the frontal cortex to age 17 (Paus, 1999). In contrast, grey matter (GM) density peaks around age 12 in dorsal frontal and parietal lobes, and around age 16 in the temporal lobe, then gradually declines (Giedd et al., 1999; Sowell et al., 1999). Such age-related changes in WM and GM density during adolescence are thought to reflect two maturational events: axonal myelination (Yakovlev & Lecours, 1967) and synaptic reorganisation (Huttenlocher, 1979). See section 1.5 of the Introduction for further description of these processes. This maturation is thought to increase neural efficiency within developing areas (Blakemore & Choudhury, review 2006), and be responsible for changes in activation of regions of the frontal cortex such as the prefrontal cortex (PFC) seen with age on various cognitive tasks (e.g. Casey et al., review 2000; Monk et al. 2003; Blakemore et al., 2007; see section 1.5.3 of Introduction for description of these studies). Increased activity in the PFC has been found between childhood and adolescence during tasks of basic emotion recognition (e.g. Killgore et al. 2001; Yurgelun-Todd & Killgore, 2006). Killgore et al. (2001) presented 19 children and adolescents aged from nine to 17 years old with pictures of fearful faces in an fMRI scanner. The results indicated that, for females only, increased activation in dorsolateral PFC occurred in response to fearful faces with age (Killgore et al., 2001). This is consistent with a later study by Yurgelun-Todd and Killgore (2006) whereby increased PFC activity in response to fearful faces was found between the age of eight and 15.

Such increased activation in the PFC during tasks of emotion processing between childhood and adolescence may be consistent with behavioural studies finding continued development of executive function abilities associated with the PFC (Goldman-Rakic et al., 1996). These studies have shown developmental trajectories consistent with both myelination and synaptic reorganisation, posited to be responsible for WM and GM density change in regions such as the frontal and temporal lobes during adolescence (see section 1.5.4 of the Introduction for further description). As regions of the frontal and temporal cortices show activation during basic emotion processing in adults (Sprengelmeyer et al., 1998; Phillips et al. 1998b; Kesler-West et al., 2001), similar development may be found for basic emotion processing during adolescence.

The development of basic emotion processing was therefore investigated, in a group of females aged 9.06 to 16.04 years. Two computer tasks of basic emotion recognition were employed: the Ekman pictures of facial affect task (Ekman & Friesen, 1976) and an animations task developed by Boraston et al. (2007). Both tasks involved the presentation of emotional stimuli, and required nonverbal, multiple choice-type responses. However, the animations task presented abstract geometric shape stimuli that moved in a dynamic way, for example, a triangle and a circle moving as if they are chasing or teasing each other. The response was based on judging degree of emotional intensity. In contrast, static human face stimuli were presented in the Ekman task, with response being based on the selection of one out of a possible six emotions. This allowed investigation of basic emotion processing using two different non-verbal paradigms. While the results of behavioural studies suggesting basic emotion processing to be completed by late childhood (Ekman et al., 1980; Durand et al., 2007) were acknowledged, the continued maturation of the frontal and temporal cortices associated with basic emotion processing in adults led to the prediction that further change basic emotion recognition may occur during adolescence. Two patterns of development were possible: i. development may be linear, consistent with myelination and WM density, or ii. development may follow an inverted U shaped pattern, consistent with synaptic reorganisation and non-linear GM density change, in the frontal and temporal cortices during adolescence. Puberty rather than chronological age was used based on evidence that pubertal hormones crucially affect brain development and behaviour (e.g. Romeo, 2003) and that maturation is only indirectly related to age (Wetzel, 1941; Krogman, 1950).

6.5 Method

6.5.1 Participants

70 females aged 9.06-16.04 were divided into three puberty groups: pre puberty (n= 19, mean age 11.16±0.3, range 9.06-13.09 years), mid puberty (n= 34, mean age 12.67±0.21, range 10.06-14.08 years), and post puberty (n= 17, mean age 14.76±0.18,

range 13.08-16.04 years) based on the results of a developmental questionnaire (see Appendix A) adapted from Carskadon & Acebo (1993). They were recruited through letters to parents which were distributed at school. Parental and participant consent was obtained prior to the study commencing, and the study was approved by the local ethics committee. The British Picture Vocabulary Scale (BPVS; Dunn et al., 1997) was carried out with each school-aged participant individually and the data were used as an estimate of verbal intelligence. A standardised score was obtained for each participant and used to ensure that there were no outliers (i.e. participants who had +/- 5 standard deviations from the mean standardised score) based on verbal ability.

6.5.2 Design

Participants were tested individually. Presentation order of the two tasks was counterbalanced between participants.

6.5.2.1 Ekman pictures of facial affect (Ekman & Friesen, 1976).

A set of 60 pictures of faces (six female, four male) depicting expressions of six basic emotions (happy, sad, angry, scared, disgusted, surprised) was presented to participants on a Dell Latitude 100L laptop computer with a 15” LCD display screen. The pictures were in black and white, with 10 pictures for each emotion (one presentation of each emotion by each of the 10 actors). Presentation of pictures was randomised. An example set of faces displaying the six emotions is presented in Figure 6.1.

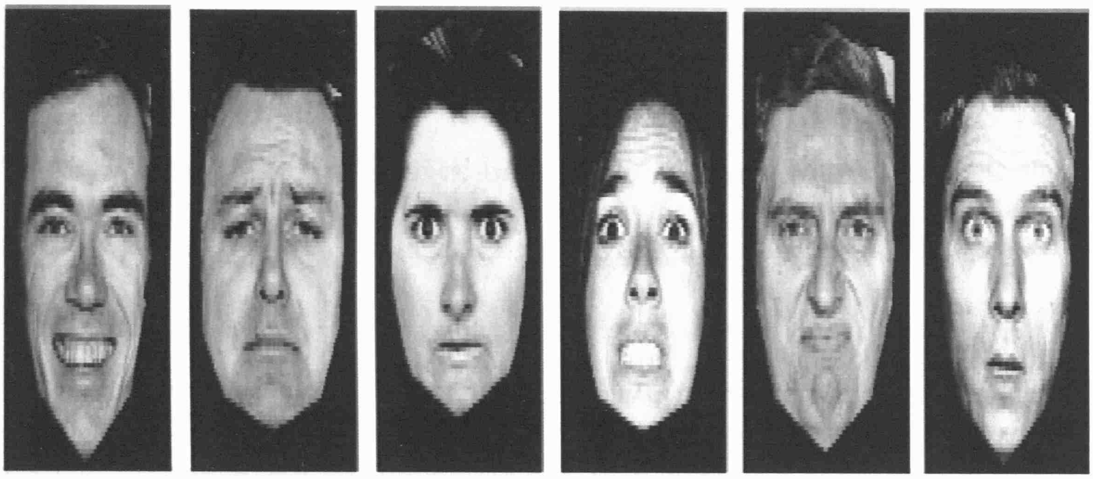

Figure 6.1: Example set of the six emotional expressions (from left to right: happy, sad, angry, scared, disgusted, surprised) in the Ekman pictures of facial affect task (Ekman & Friesen, 1976).

Participants were asked to select one of the six emotions (happy, sad, angry, scared, disgusted, surprised) they felt most accurately matched the expression in the face. Responses were made by using the computer mouse pad to select the appropriate emotion on the computer screen. Accuracy was recorded as the dependent measure, with a maximum score of 10 for each emotion.

6.5.2.2 Animations (Boraston et al., 2006)

Eight silent animations were used, with two examples of each of the four emotions. Each animation featured a black outline triangle and a black outline circle moving on a white background (see Figure 1) and were approximately 5 seconds in length (mean length = 5.4 ± 0.2 seconds). While the trajectory of the circle was identical in all eight animations, the triangle moved in a self-propelled, non-linear manner, designed to evoke the impression that it was 'living' or animate (Scholl & Tremoulet, 2000, Blakemore et al. 2003). In addition, the animations were designed to evoke the attribution of a particular basic emotion (angry, happy, sad, or scared) to the triangle. Animations were designed using Flash MX 2004, and presented to the subject using Matlab v6.5, and Cogent Graphics, on a laptop computer with a 15" LCD display screen. See Figure 6.2 and http://www.icn.ucl.ac.uk/sblakemore/ for further examples of the stimuli.

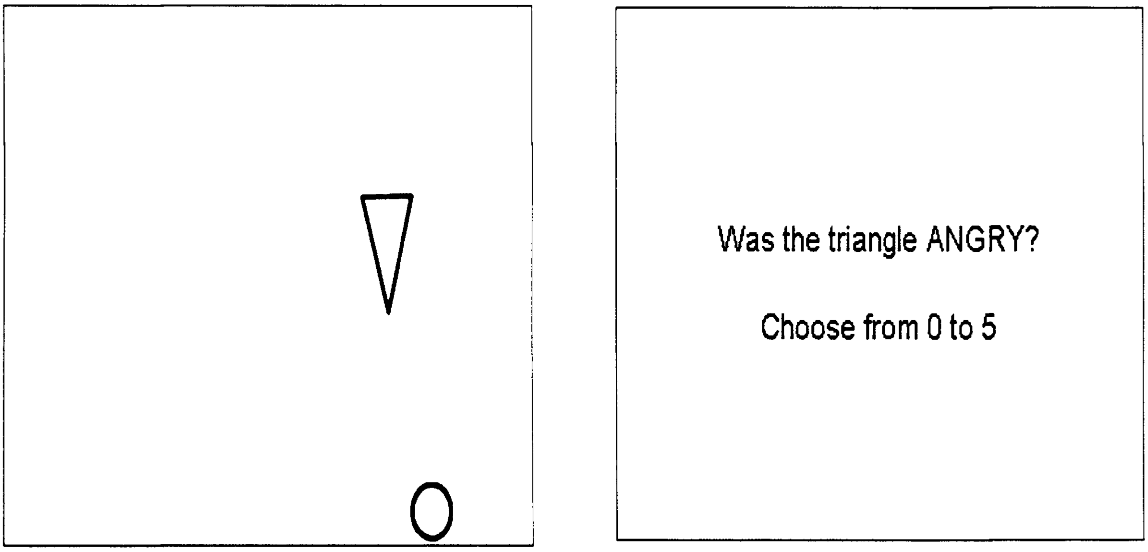

Figure 6.2: Example of animation screen and following question. The trajectory of the circle remained the same in all eight animations, while the trajectory of the triangle changed depending on the type of emotion (angry, sad, happy, scared) aimed to be invoked by viewing the animation. Accuracy was measured as the dependent measure, with a maximum score of 5 for each emotion.

Participants were first presented with a control task consisting of four animations. Participants were asked to indicate, using a 0-5 rating scale on the laptop keypad, the position (with 5 being at the top of the screen, 0 being at the bottom) of the triangle at the end of each animation. Participants then performed a practice task, whereby an animation was presented followed by an emotion question. Participants were asked to use the rating scale (5 at the top of the screen, and 0 at the bottom) to indicate the intensity of emotion they felt had been depicted in the animation. Emotion questions were of the format 'was the triangle ANGRY?'. This procedure was performed twice: once for 'anger' and once for 'scared'. The control and practise tasks were designed to ensure that participants understood the animations, and were able to use the rating response procedure appropriately. Participants who did not complete these tasks correctly were excluded.

The experimental task was then presented on the screen. Participants viewed each of the eight animations twice, making a total of 16 presentations (two presentations of each of the two examples of angry, happy, sad, or scared), in a pseudorandom order. After each presentation of an animation, an emotion question appeared on the screen, asking about the intensity of emotion portrayed in the animation. For one presentation of the animation, the question referred to the actual emotion intended to be perceived in the animation. For the other presentation of the animation, the emotion question referred to an alternative emotion that was not intended to be perceived. Participants answered emotion questions using a rating scale from 0 ("not at all...") to 5 (extremely...") by pressing corresponding keys on the computer keyboard.

6.5.3 Analysis

6.2.3.1 Ekman pictures of facial affect (Ekman & Friesen, 1976)

Responses were calculated as either correct or incorrect. Mean scores for each puberty group were then calculated, and analysed using an ANOVA with a between-group factor of *Puberty* (pre-, mid- and post-) and a within-subject factor of *Emotion Type* (happy, sad, angry, scared, disgusted, surprised). Polynomial contrasts (linear/quadratic; see Chapter 3 for description) were used to investigate the pattern of performance in empathising and systemising across adolescence.

6.5.3.2 Animations (Boraston et al., 2006)

Participants were judged on how accurate they were at identifying the correct emotion from the animation. For each pair of animations, i.e. an example of an emotion animation with an actual and an alternative emotion question, the rating given in response to the alternative emotion was subtracted from the rating given in response to the actual emotion. Subtraction of the response to the actual and alternative emotion allowed a measure of accuracy of recognising the intended emotion, giving an *emotion score*. As high ratings (5 = 'extremely…') depicted more intense feelings of emotion recognition, and low ratings (0 = 'not at all…') depicted less intense emotion recognition, larger difference scores between ratings of actual (where correct identification of this emotion in the animation would lead to a high rating) and alternative (where correct identification that this emotion is not depicted in the animation would lead to a low rating) emotions, resulted in higher (more accurate) emotion scores. As there were two animations designed to depict each of the four emotions, and each emotion was presented twice, a difference score was calculated for each actual and alternative presentation, and divided by two, to get a mean emotion score for each participant. Individual emotion scores were then averaged within puberty groups to get a mean score for each emotion in each group.

Mean emotion scores for each puberty group were analysed using an ANOVA with a between-group factor of *Puberty* (pre-, mid- and post-) and a within-subject factor of *Emotion Type* (angry, happy, sad and scared). Polynomial contrasts (linear/quadratic; see Chapter 3 for description) were used to investigate the pattern of performance in empathising and systemising across adolescence.

6.6 Results

No participants were excluded from the analysis on the basis of BPVS score or task performance.

6.6.1 Ekman pictures of facial affect (Ekman & Friesen, 1976).

Mean scores out of 10 for each of the six basic emotions on the Ekman task across puberty are given in Figure 6.3. ANOVA revealed a significant effect of emotion ($F_{(5,355)}$=40.298, $p<.0001$). There was no significant main effect of puberty ($F_{(2,67)}$=.274, $p>.05$), nor significant interaction between type of emotion and puberty ($F_{(10,335)}$=.932, $p>.05$).

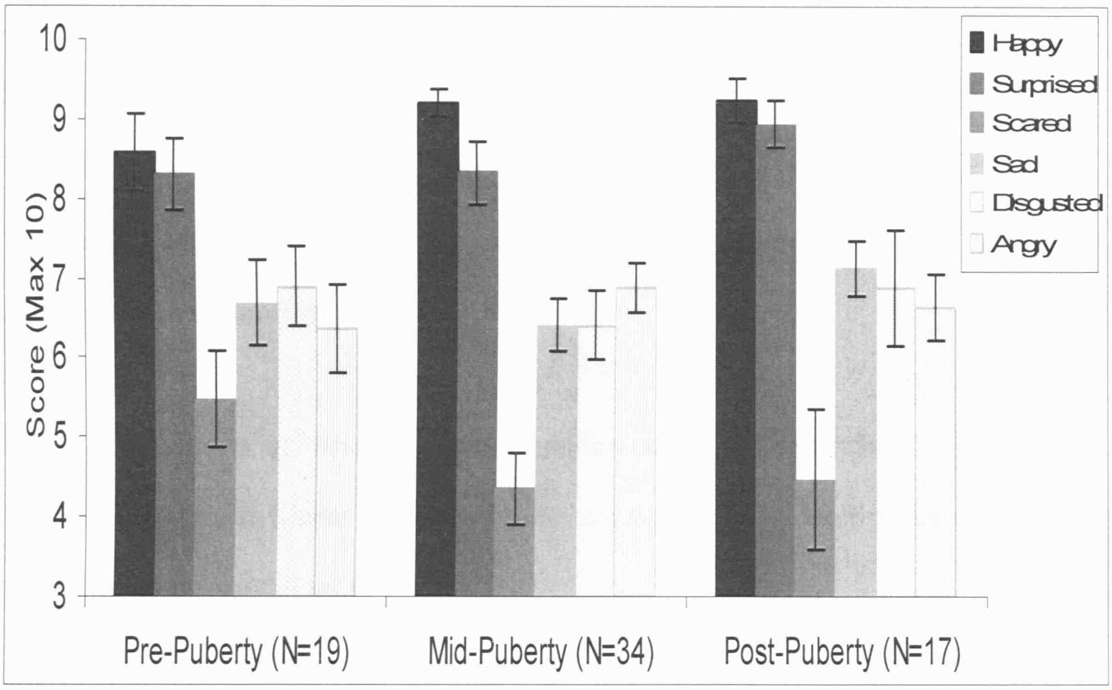

Figure 6.3: Mean scores for each emotion across puberty groups in the Ekman task (Ekman & Friesen, 1976). The maximum score for each emotion was 10.

6.6.1.1 Between-group Comparisons

There were no significant differences between puberty groups for any of the emotions ($p>.05$).

6.6.1.2 Within-group comparisons

Post-hoc within subjects simple effects analyses revealed that in all three puberty groups, significantly higher scores were demonstrated for happy than scared, sad, angry (all $p<.0001$), and disgusted ($p<.05$). All three puberty groups also demonstrated significantly higher scores for surprised than scared (all $p<.0001$), angry (all $p<.0001$), sad (pre- and post-puberty: $p<.05$, mid-puberty: $p<.0001$), and disgusted (pre-puberty: $p<.05$, mid-puberty: $p<.0001$, post-puberty, $p<.005$). In addition, the mid-puberty group demonstrated significantly higher scores for happy than surprised ($p<.005$). The mid- and post-puberty groups also demonstrated significantly higher scores for sad, disgusted (both $p<.001$), and angry ($p<.0001$), than scared. No other significant differences were found ($p>.05$).

6.6.1.3 Development of basic emotion recognition across adolescence

Polynomial contrasts (linear or quadratic) did not significantly describe the data for any of the four emotions (all $p<.05$).

6.6.2 Animations (Boraston et al., 2006)

Mean scores for the four basic emotions on the animations task for each puberty group is presented in figure 6.4 below. ANOVA revealed a significant effect of emotion type ($F_{(3,201)}$=5.721, p<.001). There was neither a significant main effect of puberty ($F_{(2,67)}$=1.237, p>.05), nor a significant interaction between emotion type and puberty ($F_{(6,201)}$=.256, p>.05).

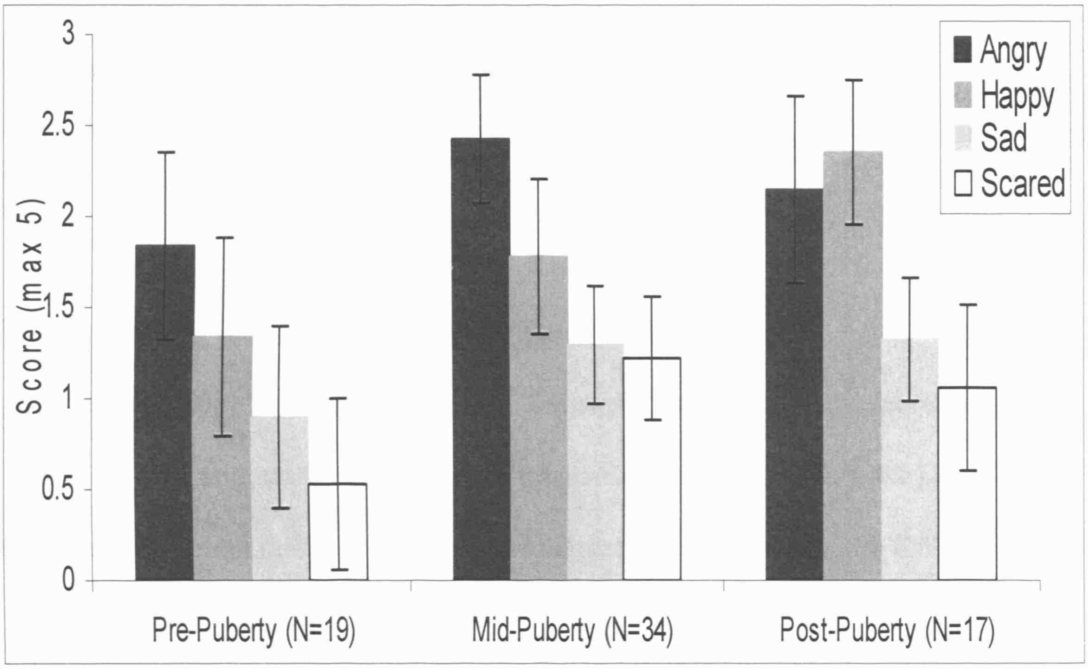

Figure 6.4: Mean emotion scores on animations task across puberty. The maximum score for each emotion was 5.

6.6.2.1 Between-group Comparisons

There were no significant differences between puberty groups for any of the emotions (p>.05).

6.6.2.2 Within-group comparisons

Simple effects analyses revealed significantly higher scores for angry than scared in the pre- and mid- puberty groups (both $p<.05$). In addition, the mid-puberty group demonstrated significantly higher scores for angry than sad ($p<.05$). In the post-puberty group, higher scores for happy than scared approached significance ($p=.059$). No other significant differences were found ($p>.05$).

6.6.2.3 Development of basic emotion recognition across adolescence

Polynomial contrasts (linear or quadratic) did not significantly describe the data for any of the four emotions (all $p>.05$).

<u>6.6.3 Correlation between Ekman and animations tasks</u>

Significant positive Pearson correlations between overall accuracy scores for fear on the Ekman task and scared (fear) on the animations task (see Figure 6.5), and between angry on the Ekman task and angry on the animations task (see Figure 6.6), were found (Fear: $r=.263$, $p<.05$; Anger: $r=.260$, $p<.05$;).

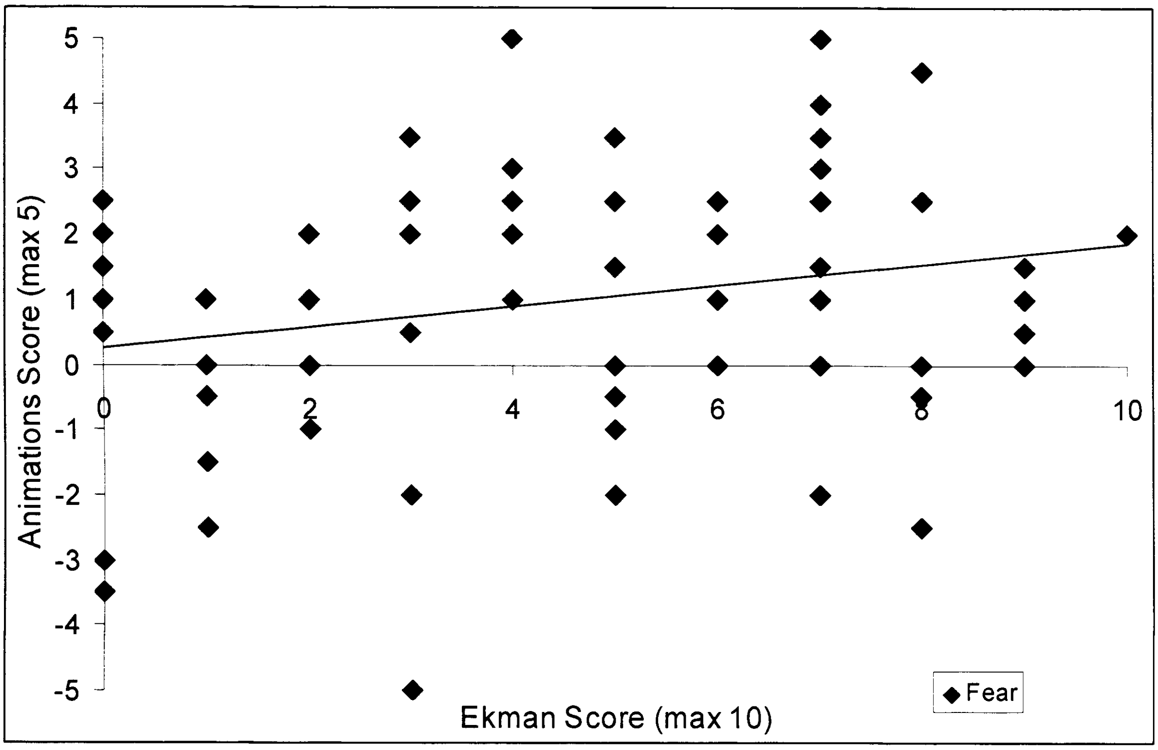

Figure 6.5: Significant positive correlation between scores for the emotion fear on the Ekman and animations tasks.

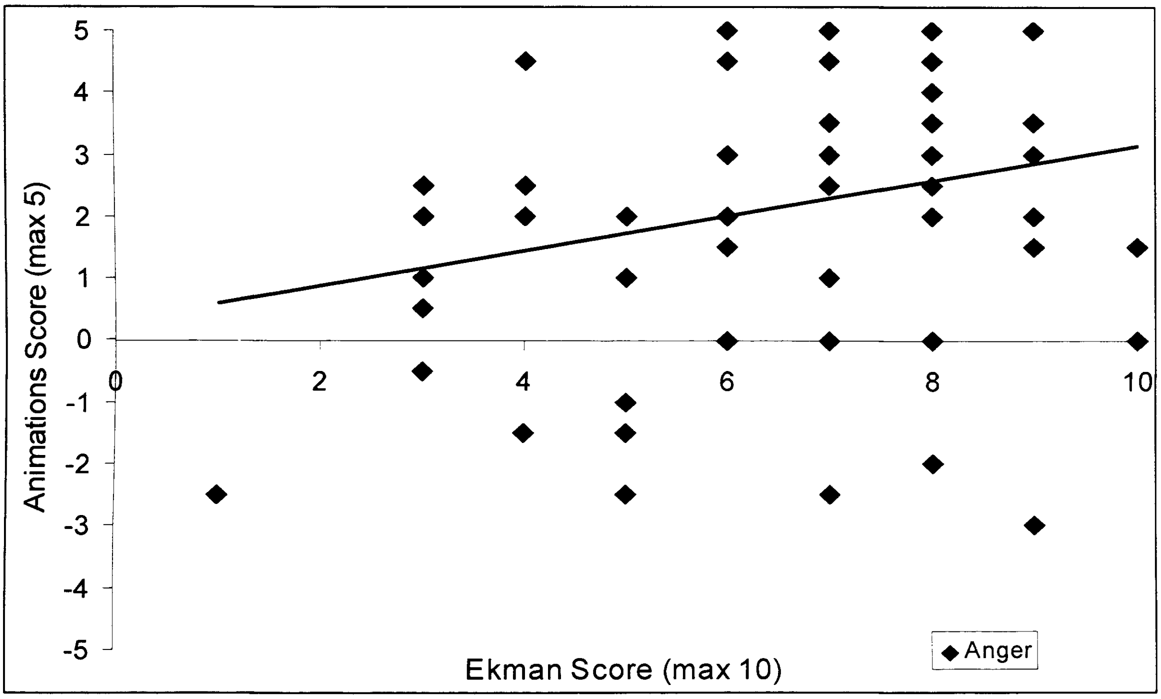

Figure 6.6: Significant positive correlation between scores for the emotion anger on the Ekman and animations tasks.

6.7 Discussion

The aim of the current study was to investigate the development of basic emotion recognition during adolescence. This was investigated through the use of two basic emotion tasks: one involving animations designed to elicit attributions of the emotions happy, sad, angry, and scared; the other the Ekman pictures of facial affect task (Ekman & Friesen, 1976) with happy, sad, fear, surprise, disgust, and anger.

While a study by Durand et al. (2007) involving basic emotion recognition in children suggested adult-like levels of performance by age 11 years, there has been little research investigating this ability in adolescence. This is despite adolescence being a time of emotional instability (Larson et al., 2002). In addition, protracted development of frontal and temporal brain regions associated with basic emotion processing adults (e.g. Kanwisher et al., 1997; Sprenglemeyer et al., 1998) has recently been found to occur into adolescence (e.g. Giedd et al., 1999; Sowell et al., 1999). It was predicted therefore that a change in basic emotion processing may occur during this period. However, no change was found to occur in either of the current tasks, extending previous findings (e.g. Ekman et al., 1980; Durand et al., 2007) to include stability of basic emotion processing up to mid- to late- adolescence (age 16 years).

Stabilisation of basic emotion processing during childhood may be due to the cognitive simplicity of processing emotions such as anger and fear. Basic emotions may be somewhat instinctual, as suggested by the ability of infants aged three months to exhibit a number of these universal facial expressions (Izard, 1971; Izard & Malatesta, 1987). This could be due to their high evolutionary value, alerting self and others to possible dangerous (e.g. anger/fear) or rewarding (e.g. happiness) stimuli. Despite further maturation of frontal and temporal brain regions into adolescence, the development of basic emotions may therefore have already reached a maximal stage before this time.

6.7.1 Overall differences between types of basic emotion

While there was no specific effect of puberty on performance on either task, some overall differences in processing different types of basic emotion were found.

6.7.1.1 Ekman Task

Data from the Ekman pictures of facial affect task (Ekman & Friesen, 1976) indicated greater overall levels of accuracy for recognising happy faces compared to other emotions across all participants. A bias toward happiness relative to other basic emotions is consistent with previous research by Ekman et al. (1980). Their data indicated that while all children were successful at intentionally reproducing facial expressions of happiness, proficiency at other emotions such as surprise and disgust developed over time (Ekman et al., 1980). Greater accuracy on recognising this emotion may therefore reflect heightened saliency, perhaps due to earlier acquisition or recognition, of happiness relative to other basic emotions.

Imaging research with adults has also found significantly greater activation in the frontal lobes during viewing happy faces relative to other basic emotions, such as sad. For example, Phillips et al. (1998a) found significant activation in the left anterior cingulate gyrus, bilateral posterior cingulate gyri, medial frontal cortex and right supramarginal gyrus during processing of happy relative to neutral facial expressions. This activation was not found for sad relative to neutral faces. In a study assessing cerebral blood flow during processing happy and sad facial expressions, Gur et al. (1994) found significant left frontal activation in happy relative to sad conditions. Variance therefore exists as to the way in which different basic emotions are processed, consistent with past research (e.g. fear/disgust; see Adolphs, 2002), with the recognition of happiness activating the frontal cortex to a greater extent than sadness. Such neural differences, combined with the earlier acquisition of understanding happiness relative to other basic emotions, may have a positive effect on recognition accuracy of this emotion as found in the current study.

A second finding was that all participants demonstrated lower levels of accuracy for scared, sad, angry, or disgusted, than for surprised, facial expressions. Again, this is consistent with Ekman et al. (1980) who reported that while performance was stable between age 10 and 14 years, the reproduction of facial actions associated with fear, sadness, and anger, may be of particular difficulty even at age 14 years. Data from the current study may therefore extend this up to age 16.

6.7.1.2 Animations task

Data from the animations task (Boraston et al., 2006) revealed that the pre- and mid-puberty groups were significantly more accurate for angry than scared animations. The mid-puberty group were also more accurate at recognising angry than sad animations. As with the Ekman task, this could be due to variability in processing different types of basic emotion. In a study investigating the perceived intensity of caricatured faces, Calder et al. (2000) compared the intensity of emotions against neutral faces, and found higher ratings for anger than for fear in adult participants. In the current animations task, movement patterns during angry animations, where the triangle repeatedly 'jabbed' at the circle, may have been more intense and pronounced than movement patterns of scared (where the triangle appeared to 'run away' from the circle) or sad (where the triangle appeared to 'push away' the circle) animations. Anger may have therefore been more readily recognised than fear or sadness, resulting in higher levels of accuracy for this emotion. While inspection of the means suggests a similar tendency toward higher accuracy for angry than scared or sad in the post-puberty group, this did not reach significance. It may be that these more mature participants had less intense or less differentiating responses to the different types of emotion animations, consistent perhaps with research finding attenuation to emotional intensity in older people (Williams et al., 2006). However, further research is required to assess such differences.

6.7.2 Correlation between Ekman and Animations tasks

Positive correlations between accuracy for anger and fear were found between the two tasks. This suggests that individuals who were more accurate on one task were also more accurate on the other for these emotions. This relationship was not found for the other emotions common to both tasks, i.e. happy and sad. This could have been due to the abstract nature of stimuli used in the animations task, relative to the pictures of facial expressions in the Ekman task, which may have differentially affected performance for angry and scared compared with happy and sad emotions. The fast movements used to evoke angry and scared emotions in the animations task may have been more easily recognisable than the less vigorous movements associated with happy and sad. This could have affected (i.e. lowered) accuracy for these emotions relative to angry and scared in this task. In contrast, recognition of happy and sad emotion from facial expressions as used in the Ekman task may have been more easily recognisable.

It has already been mentioned that happy and sad are among the first emotions to be expressed by infants (e.g. Izard, 1971), and a bias toward happiness has been found in basic emotion processing (e.g. Ekman et al., 1980). However, these differences were not found to be significant between puberty groups, and due to the preliminary nature of the current data further research is required to investigate these findings.

6.8 Future Directions

This study did not find any differences in basic emotion processing during adolescence. It may be that this ability reaches a maximal level during late childhood, despite further cortical development of regions associated with basic emotion processing in adults, during adolescence. Alternatively, the use of more sensitive measures of emotion recognition may enable detection of subtle changes in performance during adolescence. For example, the use of response time as used by McGivern et al. (2002) who found a decrement in speed of response at puberty on a match to sample-type task involving emotions, could be a useful method of detecting subtle changes in response to basic emotions during adolescence.

6.9 Summary

This study aimed to investigate whether basic emotion processing changed over the course of adolescence. Viewing facial expressions of basic emotions such as fear and anger relative to neutral facial expressions in adults is associated with regions of the frontal and temporal cortices (Sprengelmeyer et al., 1998; Phillips et al., 1998b; Kesler-West et al., 2001). These regions show protracted development into adolescence (Giedd et al., 1999; Sowell et al., 1999), and it was hypothesised that this may impact on basic emotion processing during this time. This was investigated using two non-verbal tasks:

i. the Ekman pictures of facial affect (Ekman & Friesen, 1976) presenting pictures of faces expressing six basic (happy, sad, fear, anger, disgust, surprise) emotions, and ii. An animations task (Boraston et al., 2006) presenting inanimate objects moving in ways evocative of four basic emotions (anger, fear, happy, sad). However, contrary to the prediction of developmental change and consistent with a number of studies finding stabilisation of basic emotion by late childhood (e.g. Ekman et al., 1980; Durand et al., 2007), no further change was found in the ability to recognise basic emotion on either task. This suggests that basic emotion processing may be completed during late childhood, extending previous research of stabilisation of basic emotion processing up to age 16 years.

Next, the development of a second category of emotion known as 'social' emotion was investigated. Unlike basic emotions, social emotions such as embarrassment and guilt are often strongly defined by cultural norms, and have an inherent mentalising component. Consistent with this is imaging research with adults showing *preferential* activation of key regions of the social brain network, namely the PFC and STS, during processing social relative to basic emotions (e.g. Moll et al., 2002a;b). Investigation of social emotions during adolescence may therefore provide a more sensitive measure of emotional change due to protracted frontal and temporal brain development during adolescence than basic emotions. An investigation of whether further developmental complexity in processing social relative to basic emotion during adolescence is presented in the next chapter.

CHAPTER 7

DEVELOPMENT OF MIXED SOCIAL EMOTION DURING ADOLESCENCE

7.1 Social emotion develops after basic emotion

Social emotions such as embarrassment and guilt require an ability to represent other people's real or imagined mental states. For example, to feel embarrassed you need to believe that other people think your actions foolish. To feel guilt you need to believe that other people judge your actions as wrong. Such mental state representation is one aspect of 'Theory of Mind' (ToM; Premack & Woodruff, 1978) or mentalising (Frith & Frith, 2003). In contrast, basic emotions such as fear and anger can be experienced without representing other people's mental states. Social emotions are also often strongly defined by social norms, i.e. socially constructed and enforced rules governing behaviour, while basic emotions are universally recognised across cultures (Ekman, 1972; 1999). Perhaps as a result of the dependence on social norms and inherent mentalising component, social emotions appear to develop later in childhood than basic emotions (e.g. Harris et al., 1987). Infants in the first few months of life exhibit facial expressions associated with basic emotions such as happy and sad (Izard, et al., 1980), and the ability to recognise and report on basic emotions is in place by age five (Bretherton et al., 1986). However, Harris et al. (1987) found that seven year olds but not five year olds were able to think of situations that would plausibly elicit social emotions such as pride, jealousy and guilt.

7.2 Development of 'mixed' emotion

A second conceptual dimension in emotion understanding is the ability to acknowledge that a number of discrete emotions may be elicited by a single event. Harris (1989) has described this as 'mixed emotion'. Mixed emotions may be similar in valence, such as feeling both anger and sadness at a missed opportunity; or they may be felt as a mixture of positive and negative emotion, for example feeling happy and angry upon the safe return of a wayward child. This mixing of positive and negative emotion is known as emotional 'ambivalence' (Ainsworth et al., 1978), and is shown by infants as young as one year old when they are separated and then reunited with their mothers (Ainsworth et al., 1978; see also Campos et al., 1983). It has been suggested that mixed emotion understanding emerges as children learn to interpret the emotional reactions that they already express, through an increasingly mature appreciation of the complex causal relationships between situations and emotions (Harris 1989).

An appreciation of mixed feelings involving basic emotions such as happy and sad appears to be in place around age 10 to 12 years (Harter, 1983; Harter & Buddin, 1987; Larsen et al., 2007). Larsen et al. (2007) presented a group of children aged between five and 12 years with a video clip from a popular children's fairy tale. Children viewed a 'bittersweet' scene in which the father character is portrayed as having to say farewell to his daughter. There was a significant effect of age on both the expression of awareness of the father having experienced mixed positive and negative basic emotions, and the tendency to personally experience mixed emotions. These data indicate that, in addition to developing a better conceptual understanding of mixed emotion, young adolescents also demonstrate a greater likelihood than pre-adolescent children of experiencing mixed emotions in emotionally complex situations (Larsen et al., 2007). This development may also be linked to development of counterfactual reasoning ability, since a single situation must be interpreted in different ways for it to yield a mixed emotional evaluation. It has been proposed that counterfactual reasoning continues to develop beyond middle childhood and into adolescence (Baird & Fugelsang, 2004).

However, little research has investigated mixed emotion processing past late childhood, particularly the development of mixed understanding of social emotions. In addition, the causal links between situation and emotion may be more complex for social emotions than for basic emotions. Mixed emotion understanding may therefore mature later in development for social than basic emotions.

7.3 Neural correlates of social emotions in adults

A number of imaging studies have associated social emotion processing in adults with activation of the prefrontal cortex (PFC) (e.g. Berthoz et al., 2002; Moll et al., 2002a;b; Moll et al., 2005; Winston et al., 2002). Investigating the social emotion of indignation, Moll et al. (2005) found significant activation of the medial and lateral orbitofrontal cortex (OFC) in response to reading stories evocative of indignation (e.g. 'As you arrived home, you saw that the nurse had put a spider on the baby's face') relative to neutral (e.g. 'You went to the museum and paid for being taught about antiques') stories. Berthoz et al. (2002) investigated brain activation during thinking about embarrassing scenarios. Participants were scanned while reading short stories involving intentional (e.g. spitting out food at a dinner party because you dislike the taste) or unintentional (e.g. choking on food at a dinner party and spitting it out) social transgressions. Compared to matched stories in which no transgression occurred, and consistent with social emotions having an inherent mentalising component, similar activation was found for both unintended (embarrassing) and intended social transgressions. Specifically, increased activation in the medial superior prefrontal cortex (PFC), left middle and inferior PFC, left OFC, anterior temporal pole bilaterally, left temporo-parietal junction and occipital cortex, was found for both types of social transgressions relative to control stories (Berthoz et al., 2002).

Regions of the frontal cortex have also been associated with basic emotion processing (e.g. Sprengelmeyer et al., 1998; Kesler-West et al, 2001; see Chapter 6). However, *preferential* involvement of regions of the social brain network associated with mentalising including the PFC and superior temporal sulcus (STS) has been found during processing social relative to basic emotions (Moll et al., 2002a;b). Moll et al. (2002b) compared responses to scenes involving either basic emotions (fear and disgust) or socio-moral emotions (compassion and indignation), where an evaluation of 'right' or 'wrong' is based upon social norms. Increased activation of the right medial OFC, medial frontal gyrus, and the cortex surrounding the right posterior STS was found in the socio-moral compared with basic emotion conditions. Comparing socio-moral with basic emotion conditions also showed an increase in functional connectivity between these regions, emphasising a central role for these regions in social relative to basic emotions (Moll et al., 2002b). Moll et al. (2002a) also found preferential activation of the medial OFC and posterior STS during judgements of written statements involving the same socio-moral verses basic emotions. Social emotions therefore appear to engage regions such as the PFC and STS to a greater extent than basic emotions in adults.

7.4 Investigation of mixed social emotion during adolescence

Adolescence is a time of acute socio-emotional change. For example, young adolescents aged around 13 years tend to be more self-conscious than children or older adolescents (Simmons et al., 1973; Elkind & Bowen, 1979). This may indicate that young adolescence (during mid- puberty) is a time of increased awareness of social emotions such as embarrassment. In addition, the PFC and STS show protracted development into adolescence (e.g. Giedd et al., 1999; Paus et al., 1999; Sowell et al., 1999). This neural development may impact on the way social emotions are experienced or evaluated during this time. Several studies have shown that neural development follows a non-linear (inverted U shaped) time-course, with a peak in grey matter (GM) volume occurring at around the onset of puberty in the frontal cortex, followed by a protracted period of cortical thinning (e.g. Giedd et al., 1999). At the cellular level these gross changes are thought to reflect synaptogenesis and synaptic pruning, respectively (Huttenlocher, 1979). This inverted U shaped trajectory is also seen in the temporal cortex (Toga et al., 2006). At the same time, a linear increase in overall white matter (WM) density has been observed to occur over the period of adolescence (Giedd et al., 1999; Paus et al., 1999). This process is thought to reflect myelination (Yakovlev & Lecours, 1967). See sections 1.5.1 of the Introduction for full description of these processes

Such protracted cortical maturation has been associated with changes in brain activation observed over the course of childhood and adolescence (e.g. Killgore et al. 2001; Yurgelun-Todd & Killgore, 2006 - see section 1.5.3 of Introduction for further description of these studies). In addition, behavioural research has indicated both linear (e.g. Anderson et al., 2001; Luna et al., 2001; Tamm et al., 2001) and inverted U shaped (e.g. McGivern et al., 2002) development of executive function, also associated with regions of the frontal cortex such as the PFC (Goldman-Rakic et al., 1996), over the course of adolescence (see section 1.5.4 of Introduction).

A self-report questionnaire was therefore developed to investigate the development of social relative to basic emotion during adolescence. This task presented scenarios designed to evoke social emotions (embarrassment and guilt) and basic emotions (fear and anger). Female participants aged 9.06 to 16.04 years were asked to imagine experiencing each scenario and report how strongly they would feel each of the four emotions. This enabled a measure of mixed (simultaneous) emotion for the social and basic emotion scenarios. However, mixed emotional responses were not discussed with participants, and neither was the distinction between social and basic emotion: as a result this study provides a largely implicit measure of mixed emotion understanding for social and basic emotion. Participants were grouped by puberty, rather than chronological age, on the basis of evidence that pubertal hormones crucially affect brain development and behaviour (e.g. Romeo, 2003) and that maturation is only indirectly related to age (Wetzel, 1941; Krogman, 1950).

Based on increased self-consciousness during adolescence (Simmons et al., 1973; Elkind & Bowen, 1979), preferential activation of key regions of the social brain (PFC and STS) for social relative to basic emotions (Moll et al., 2002a;b; Moll et al., 2005), and the neural changes that occur during puberty, it was predicted that reporting of simultaneous or 'mixed' emotion would change across puberty for the social emotions only. Two possible patterns of change were predicted for the social emotion scenarios: linear or inverted U shaped. If development was linear, progressive increases in mixed emotion reporting would occur over adolescence for social but not basic emotions, consistent with WM maturation in regions such as the PFC during this time. Alternatively, if there is an inverted U shaped pattern of change in mixed social emotion reporting, it may decline at puberty and then increase during post-puberty, consistent with GM change during this time. In contrast, no change in basic emotional processing was predicted. This was due to previous research, including a study in this thesis (see Chapter 6), where abilities pertaining to basic emotions appear to be completed by late childhood (Ekman et al., 1980; Durand et al., 2007).

7.5 Method

7.5.1 Participants

86 female subjects aged 9.06 to 16.04 years old took part in the study. They were divided into three groups: pre-puberty (n = 25, mean age 11.6±1.35, range 9.06-14.01 years); mid-puberty (n = 40, mean age 13.0±1.14, range 10.06-15.04 years) and post-puberty (n = 21, mean age 15.2±0.69, range 13.08-16.04 years) based on a physical development questionnaire (see Appendix A) adapted from Carskadon & Acebo (1993). For the primary school age participants (aged 9-11), development

questionnaires were posted to the parents of each participant to be completed either by the parent, the parent and child or the child alone, depending upon parental preference. For the secondary school age participants (aged 11-16), the school administered the developmental questionnaire under exam-like conditions and with parental consent. Data obtained from these questionnaires were used to assign participants to one of the three puberty groups. Participants were tested at their schools in Birmingham, UK, and all were of similar socio-economic background. Recruitment was through letters distributed by the schools. Parental consent and participant assent was obtained prior to testing. The study was approved by the local ethics committee.

7.5.2 Design

Participants were given a sheet of paper with a series of sentences and emotional rating scales. Each item, consisting of two sentences, was read aloud to participants, who were asked to imagine how they would feel if the scenario described happened to them. Each scenario was designed to evoke one of four emotions: embarrassment or guilt (social emotions) and fear or anger (basic emotions). There were 32 scenarios in total, of which there were 16 social emotion scenarios (eight guilt; eight embarrassment) and 16 basic emotion scenarios (eight anger; eight fear). An example of a guilt scenario is: "You were meant to look after your little brother but you went out. When you got back he was crying". An example of an embarrassment scenario is: "You ate too many sweets at a party. You threw up in the living room in front of your friends". An example of an anger scenario is: "You were standing in the dinner queue. Someone pushed in front of you". An example of a fear scenario is: "You were riding your bike down a hill.

Suddenly, your brakes stopped working". Further examples are presented in Appendix C.

After each scenario was read to participants, they were asked to imagine how they would feel and use the rating scale presented beneath the scenario on their task paper to indicate how much they would feel each emotion (guilt, embarrassment, anger and fear), by placing a mark from 0 (not at all) to 10 (very strongly). To encourage use of the whole scale, participants were asked to circle either 0 (if they would not feel a particular emotion at all) or 10 (if they would feel a particular emotion very strongly), or to place a single line anywhere along the scale from 0 to 10, for each emotion. Number of emotions, rather than ratings per se, was investigated to obtain a measure of mixed emotion. An example of a task question and a response is presented in Figure 7.1 below.

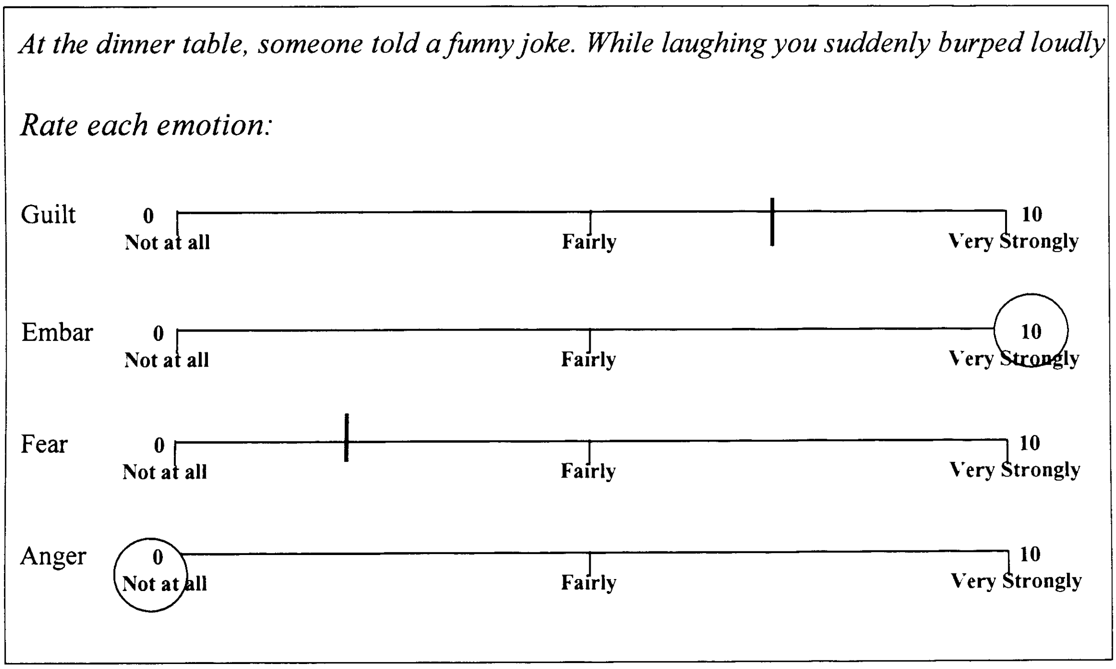

Figure 7.1: Example of task question (evocative of embarrassment) and response. As there are three emotions rated above 2cm, this item would be given a score of '3' (see analysis).

The order of emotion words for each scenario was randomised within and between participants. The order in which scenarios were presented was randomised between participants. Participants were tested in groups of up to four people separated sufficiently so they were unable to see each others' papers or confer. Before the experiment began, the researchers ensured that each participant understood the four emotions (guilt, embarrassment, anger and fear) by defining them and then asking participants to give examples of each emotion.

7.5.3 Analysis

Participants made four ratings for each scenario: one for each of the emotions (guilt, embarrassment, anger, fear) along a scale of length 10cm. These scenarios had been specifically designed to induce feelings of social (embarrassment, guilt) and basic (anger, fear) emotions, and these social/basic categorisations were consistent with a pilot study with adults. In addition, analysis of responses by adolescent participants in the present study indicated that the social emotions were rated significantly higher (more intense) than the basic emotions for the 16 social emotion scenarios, and vice verse for the 16 basic scenarios, in each puberty group (all $p<.0001$), consistent with the task design.

Despite encouraging participants to circle zero when an emotion was not felt, individual differences in the way in which questionnaires were completed made it difficult to verify indications of 'no emotion' between participants. A cut-off point of >2cm was therefore set, enabling a methodical assessment of mixed emotion reporting across participants which was more independent of response style. A rating of >2cm was chosen as ratings below this were thought to indicate very weak feeling of that particular emotion. Only 5.4% of all ratings were <2cm. For each participant and for each scenario, the mean number of times a rating of 2cm or higher had been selected for the 16 social and 16 basic emotion scenarios was calculated. As there were four emotions in each item, this score was between 0-4 (0 = no ratings >2cm, 4= four ratings >2cm). Scenarios in which none of the four emotions were rated as >2cm were omitted from the analysis as this was considered to be indicative of an absence of emotion. The mean number of times a rating of >2cm had been selected across social and basic emotion scenarios was calculated for each participant, resulting in a mean mixed emotion score for social emotions and basic emotions for each participant in each group.

Differences in these mixed emotion scores across the three puberty groups for the social and basic emotions were investigated using ANOVA with a between-subjects factor of *Puberty* (pre-, mid- and post-) and a within-subjects factor of *Emotion Type* (social, basic). Simple effects analyses were used to explore differences in social and basic emotion ratings between and within puberty groups. To investigate the pattern of social and basic emotion ratings across puberty, polynomial contrasts (linear/quadratic; see Chapter 3 for description) for social and basic mixed emotion scores across puberty were performed.

7.6 Results

Mean mixed emotion scores for social and basic emotions in each puberty group are presented in Figure 7.2. ANOVA revealed a significant main effect of emotion type ($F_{(1,83)}$= 151.894, p<.0001) and a significant interaction between emotion type and puberty group ($F_{(2,83)}$= 2.739, p<.05 one-tailed). There was no significant main effect of puberty group ($F_{(2,83)}$ = 1.046, p>.05).

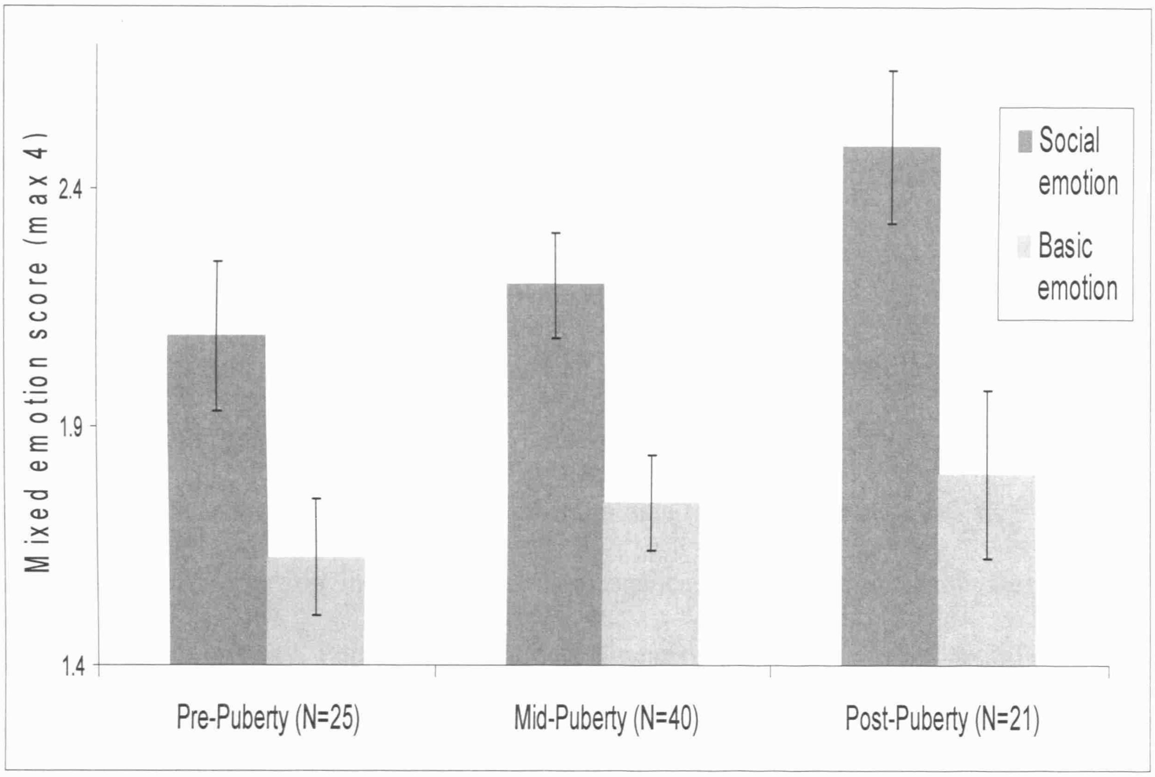

Figure 7.2: Mean mixed emotion scores for social and basic emotions in each puberty group. The maximum score was 4, with higher scores indicating greater mixed emotion reporting. There was significantly greater mixed emotion reporting for social emotions in the post-puberty than the pre-puberty group. In addition, for all puberty groups, mixed emotion scores were higher for social emotions than for basic emotions.

7.6.1 Between-subjects comparison

Between groups simple effects analysis revealed significantly greater amount of mixed emotion in the post-puberty group compared to the pre-puberty group for the social emotions only ($p<.05$, one-tailed). No other significant between-subjects differences were found ($p>05$).

7.6.2 Within-subjects comparison

Within groups simple effects analysis revealed that all three puberty groups demonstrated significantly greater amount of mixed emotion reporting for social relative to basic emotions (all groups: $p<.0001$).

7.6.3 Development of social and basic emotions across adolescence

A significant linear pattern was found across puberty for mixed emotion reporting in social emotion scenarios (1-tailed, $p<.05$). Second-order quadratic (inverted U) contrast did not significantly describe the social emotion data ($p<.05$). This suggests that mixed social emotion reporting increased over adolescence, with no significant decline in performance at puberty. Polynomial contrasts (linear or quadratic) did not significantly describe the data for basic emotions ($p>.05$).

7.7 Discussion

While basic emotions such as fear and anger are expressed during the first year of life (Izard et al., 1980), an awareness of social emotions such as embarrassment and guilt develops over the course of childhood (e.g. Harris et al., 1987). The later development of social relative to basic emotions may reflect their relative complexity, due to an inherent mentalising component and dependence on social norms. In addition, social emotions have been found to activate key regions of the social brain network including the PFC and STS to a greater extent than basic emotion processing (e.g. Moll et al., 2002a;b). These regions show protracted development into adolescence (Giedd et al., 1999; Sowell et al., 1999). The current study predicted therefore that development in mixed processing for social emotions would occur during adolescence. In contrast, no further change was expected in basic emotion processing, due to research finding stable performance on basic emotion tasks in late childhood (e.g. Ekman et al., 1980; Durand et al., 2007), and mixed basic emotion understanding developing by age 10 to 12 years (Harter, 1983; Harris et al., 1986; Harter & Buddin, 1987; Larsen et al., 2007).

7.7.1 Increased mixed social emotion processing occurs during adolescence

In line with predictions, mixed emotion processing increased over adolescence for social emotions only. No change in mixed basic emotion understanding was found, consistent with stability of basic emotion processing in late childhood (e.g. Ekman et al., 1980; Durand et al., 2007; and Chapter 6 of this thesis). In addition, current findings extend previous research on mixed basic emotions (Harter, 1983; Harter & Buddin, 1987; Larsen et al., 2007) up to age 16 years for mixed social emotions. The data also revealed significantly greater levels of mixed emotion for social compared with basic emotions in all three puberty groups, in line with social emotions being inherently more complex than basic emotions.

The results are consistent with protracted development of brain regions including the PFC and STS, which show preferential activation during social relative to basic emotion processing in adults (e.g. Moll, et al., 2002a;b; Moll et al., 2005). In particular, the linear increase in mixed emotion processing for social emotions found across adolescence is compatible with continued myelination (Yakovlev & Lecours, 1967) and its associated increased WM density in the PFC during late childhood and adolescence (Giedd et al., 1999; Sowell et al., 1999). The PFC has also shown heightened activation during adolescence relative to childhood (e.g. Killgore et al., 2001). These neural changes could lead to increasing efficiency of information processing over the course of adolescence (see Blakemore & Choudury, 2006). This could have a specific effect on social emotion processing, generating more complex socio-emotional responses and leading to social emotions being appraised in a more considered manner. This may have contributed to the higher levels of mixed emotion reported over the course of adolescence in this study. In contrast, basic emotional complexity may have reached its maximal stage by late childhood, consistent with previous research (e.g. Ekman et al., 1980; Durand et al., 2007; Chapter 6 of this thesis). This could be due to the relative simplicity of basic emotions (see section 6.7 of Chapter 6 for further discussion), perhaps reflected by lower level activation of brain regions including the PFC during processing basic vs. social emotions (Moll et al., 2002a;b).

Performance across puberty may also have been affected by factors other than neural development, including changes in steroid hormone levels, physical changes, and new socio-emotional demands. For example, Larson et al. (2002) suggested that reduced change in daily environments or experiences with age could cause greater emotional stability found in late relative to early adolescence. In addition, research by Zeman et al. (2006) found that adolescents become more able to regulate their emotions and consider the interpersonal consequences of expressing certain kinds of emotion to their parents and peers between the ages of 12 and 18 years (Zeman et al, 2006). This is consistent with Krettenauer and Eichler (2006), who suggested that socio-moral change during adolescence may be due to adolescents' emerging ability to take situational variations into consideration when responding to emotional situations. Further research is therefore required to investigate the contribution of environmental factors on socio-emotional development during adolescence.

7.8 Future Directions

Future research is required to disentangle possible causes driving the socio-emotional development found to occur over adolescence. More ecologically valid task paradigms could enable investigation of real-life emotional responses during adolescence, as the current study may be limited by its reliance on self-report data. For example, the use of dyadic interaction tasks, involving social exchanges between two people on emotive issues such as conflict, peer interaction, and so on, have long been recognised as useful tools with which ecologically valid emotion responses may be generated (Coan & Allen, 2007). More realistic emotional responses may be elicited during real verses imagined scenarios, and the inclusion of such techniques may increase the reliability of data collected. Imaging research is also required to identify the neural correlates behind the emotional changes found to occur over adolescence in the current study.

7.9 Summary

This study aimed to investigate whether any changes in complexity, or 'mixed' emotion, in social relative to basic emotion processing occurred during adolescence. Studies (e.g. Ekman et al., 1980; Durand et al., 2007) investigating the development of basic emotion processing have indicated that no further change in this ability occurs after late childhood. However, understanding of social emotions develops later than basic emotions in childhood (Harris et al., 1987), perhaps due to greater complexity of social relative to basic emotions. Research with adults has indicated preferential activation of the PFC and STS for social relative to basic emotion processing (e.g. Moll et al., 2002a,b). These regions show protracted development into adolescence (e.g. Giedd et al., 1997; Paus et al., 1999; Sowell et al., 1999), which may have a specific effect on social emotion during this time. It was hypothesised therefore that mixed emotion responding would change for social emotions only, with two possible patterns of change: i. linear, consistent with increases in WM density, or ii. inverted U shaped, consistent with changes in GM density, in regions including the PFC during adolescence (e.g. Giedd et al., 1999; Sowell et al., 1999). To test this hypothesis, a questionnaire was developed whereby participants responded to scenarios evocative of social (guilt, embarrassment) and basic (fear, anger) emotions. The number of simultaneous emotions reported for social and basic scenarios was analysed across adolescence, as a measure of mixed emotion reporting.

Consistent with the hypothesis, the amount of mixed emotion reported for social, but not basic, emotion scenarios increased during adolescence. These changes were found to be linear, compatible with progressive myelination and its associated increases in WM density in brain regions including the PFC during adolescence. The relative stability in mixed basic emotion across adolescence is consistent with research finding stability of performance on tasks involving basic emotion in late childhood (e.g. Ekman et al., 1980; Durand et al., 2007; see Chapter 6). The current data also extends previous research on mixed basic emotion in late childhood (e.g. Harter, 1983; Harris, 1989; Larsen et al., 2007), up to age 16 years for social emotions. Further research is required to fully investigate the nature and implications of these findings.

Autism spectrum disorder (ASD) is a developmental disorder characterised by marked impairments in social cognition (see Frith & Frith, 2003; 2006). While individuals with ASD have shown impaired social emotion processing (e.g. Capps et al., 1992; Heerey et al., 2003), consistent with impaired social cognitive processing in ASD, there is inconsistent research regarding basic emotion processing in these individuals. An investigation of social and basic emotion understanding using the novel emotion questionnaire developed in this thesis was conducted with a group of adults with ASD and healthy controls matched for age and IQ. This study is presented in the next chapter.

Chapter 8

SOCIAL AND BASIC EMOTION IN ADULTS WITH AUTISM SPECTRUM DISORDER

8.1 Emotion processing in autism spectrum disorders

Autism is a developmental disorder characterised by abnormalities of social interaction, impoverished verbal and non-verbal communication and restricted interests/repetitive behaviour (DSM-IV, 1994). The severity of symptoms in autism can range from highly impaired to relatively high functioning, and this continuum is referred to as Autism Spectrum Disorder (ASD; Wing, 1996). See section 1.4 of Introduction for further details. Research (Baron-Cohen et al., 1985; Happé, 1994; Baron-Cohen et al., 1997a;b) has indicated that individuals with ASD are impaired at inferring the mental states of other people, known as 'Theory of Mind' (Premack & Woodruff, 1976) or mentalising (Frith & Frith, 2003). This ability is present by approximately four years of age in typically developing (TD) children (Wimmer & Perner, 1983). However, it is often delayed or absent in children with ASD (Baron-Cohen et al., 1985; Happé, 1994).

Social emotions such as embarrassment and guilt often rely on the ability to infer mental states of other people. In healthy adults, this is reflected by activation of medial prefrontal and temporal brain regions associated with mentalising (see Frith & Frith, 2003) during attribution of social emotion (e.g. Berthoz et al., 2002; Moll et al., 2002a;b see Chapter 7). However, in line with impaired mentalising in ASD (see Frith & Frith, 2003), atypical activation of these regions occurs during social cognitive tasks (e.g. Castelli et al., 2002; Happé et al., 1996; see Chapter 2 for further description of these studies) and impaired performance on tasks involving social emotions (e.g. Bauminger and Kasari 2000; Capps et al., 1992; Heerey et al., 2003; Kasari et al., 2001; Losh & Capps, 2006) has been found in ASD.

Bauminger and Kasari (2000) found an impoverished understanding of loneliness in children with ASD relative to TD controls, consistent with an impaired ability to experience relationship-based emotions as posited by Hobson (1993) (Bauminger & Kasari, 2000). Capps et al. (1992) asked children with ASD to describe a time when they had experienced feeling the emotions happiness, sadness, pride, and embarrassment. Their results indicated that children with ASD relative to TD controls demonstrated specific difficulty with describing experiences involving the socially derived emotions of pride and embarrassment. Recently, Losh and Capps (2006) included a wider range of emotions, adding angry, afraid, disgusted, guilty, and ashamed, to the original paradigm of Capps et al. (1992). Again, impoverished description and interpretation of subjective experiences relating only to the social emotions (pride, guilt, and shame) was found in children with ASD compared with TD controls. Children with ASD also show impaired ability to recognise embarrassment and shame in other people, in line with difficulties due to these emotions having an inherent mentalising component (Heerey et al., 2003).

Basic emotions such as fear and anger are universally recognised across cultures (Ekman, 1972; 1999), and do not often involve the attribution of mental states to others. However, research regarding basic emotion processing in ASD has been inconsistent. While a number of studies have found comparable performance between children with ASD and TD controls (Capps et al., 1992, Heerey et al., 2003; Jaedicke et al., 1994; Celoni et al., 1999; Heaton et al., 1999; Losh & Capps, 2006), others have found impairment (e.g.

Jaedicke et al., 1994; Rieffe et al., 2007) on tasks involving basic emotion. For example, in the studies by Capps et al. (1992; 2006), children with ASD were able to provide as detailed accounts as control participants of situations in which they had experienced basic emotions such as happy and sad. Similarly, Jaedicke et al. (1994) found children with ASD were as able as TD controls to provide plausible situations in which they felt happy, sad, angry, scared, and worried. However, the children with ASD made fewer references to social interactions (Jaedicke et al., 1994), consistent with a recent study by Rieffe et al. (2007). Rieffe et al. (2007) also found no differences in reported intensity of feelings relating to happy, sad, anger, or fear between participant groups. Although, children with ASD denied having ever experienced one or more of the basic emotions investigated (happy, sad, anger, and fear) more often than control children, contrasting with previous studies (e.g. Capps et al., 1992; Jaedicke et al., 1994).

In addition to investigating emotional responses to 'single' emotions, Rieffe et al. (2007) investigated 'mixed' (Harris, 1989) emotion understanding, for stories involving character's experiencing more than one basic emotion (e.g. angry and scared). Mixed emotion refers to the number of simultaneous emotions felt in response to one emotional scenario (see Harris, 1989), and in typical development this understanding appears to develop earlier for basic than social emotions - see Chapter 7 for further details. Rieffe et al. (2007) presented children with ASD and TD controls with stories describing events likely to evoke mixed basic emotions. An example of a story from this task is: 'Imagine, you have a cat and you are very fond of her. You play with her a lot and she always sleeps in your room. But she has been ill for the last few days. It looks like it is her stomach. You take her to the vet "Yes", the vet says, "it is awful but I have to operate on her". "But after the operation", he says, "she will be well and healthy again and she will have no pain anymore".' Following each story, participants were told that they may feel one or more emotions in response to the story, and shown four pictures depicting happy, sad, angry, and scared faces. Participants were asked to identify the emotion(s) that they would feel if the stories event happened to them and to rate how strongly each emotion would be felt. The results indicated that children with ASD relative to TD controls reported significantly fewer numbers of simultaneous emotions, indicating an impoverished understanding of mixed basic emotion in ASD (Rieffe et al., 2007). The emotional intensity ratings suggested comparable levels of happy and fear, but lower levels of anger and sadness, in children with ASD compared with controls.

Research regarding adult performance on basic emotion tasks in ASD has been similarly inconsistent. For example, using the Ekman task of facial effect (Ekman & Friesen, 1976; see Chapter 6 for a description of this task), a number of studies have found a deficit for recognising fear in ASD (e.g. Howard et al., 2000; Ashwin et al., 2007). However, using the same paradigm, others have failed to find such impairment (e.g. Heerey et al., 2003; Boraston et al., 2006). While Heerey et al. (2003) found unimpaired recognition of all six basic emotions presented in the Ekman & Friesen (1976) task, Boraston et al. (2006) found sadness to be impaired (and not fear) in adults with ASD, emphasising the inconsistent nature of basic emotion research in ASD.

As with social cognitive tasks (e.g. Castelli et al., 2002) however, atypical cortical activation in ASD has also been found during basic emotion processing in ASD (e.g. Ashwin et al., 2007; Dapretto et al., 2006). Ashwin et al. (2007) reported differential activation of the social brain in ASD compared with controls during exposure to fear relative to neutral facial expressions. While controls showed greater activation in the left amygdala and left orbito-frontal cortex, for adults with ASD this contrast revealed greater activation in the anterior cingulate gyrus and superior temporal sulcus in adults as well as a lack of differential response in social brain regions to varying intensities of fearful expression, found in control participants in this study (Ashwin et al., 2007). This suggests that different neural processes occur in ASD relative to controls during the processing of basic emotions. However, individuals with ASD may be negatively affected by the requirement to mentalise inherent in emotion recognition paradigms (see Hill & Frith, 2003 for review).

8.2 Investigation of social and basic emotion processing in ASD

Compared with the wealth of studies investigating social and basic emotion understanding in children with ASD, relatively few studies have researched the subjective social/basic emotional experiences of adults with ASD. However, research using self-report measures to assess experiences relating to emotional disorders such as alexithymia (see section 1.4.2 of Introduction for a description) and depression (e.g. Hill et al., 2004; Berthoz & Hill, 2005) have suggested that differences in emotional understanding and experience in ASD relative to controls can been found using such methods.

A self-report questionnaire designed to assess mixed emotion understanding (see Chapter 7) was used in this study therefore to investigate the nature of subjective social and basic emotion understanding in adults with ASD compared with healthy controls. Imaging research with healthy adults has found preferential activation of the social brain network during processing of social relative to basic emotions (e.g. Moll et al., 2002a;b), and this may be due to their an inherent mentalising component. This task involved the presentation of scenarios evocative of either social (embarrassment, guilt) or basic (fear, anger) emotions. Following each item, participants were asked to imagine how they would feel and make a response for each of the four emotions using the rating scale provided on the questionnaire. The use of a non-verbal response method that was not reliant on memory in the current task aimed to decrease task demands relative to previous research such as Capps et al. (1992; 2006) and provide an alternate measure of socio-emotional processing to face recognition paradigms (e.g. Heerey et al., 2003). Similar to a recent study investigating basic emotion understanding in children with ASD (Rieffe et al., 2007), this study compared the number of simultaneous or *'mixed'* (Harris, 1989) emotions given in response to emotional scenarios by adults with ASD compared with controls. The relative intensity of social and basic emotions was also compared. In contrast to previous studies, the current task was employed with adults and included an investigation of social emotion understanding.

Due to research indicating impaired social emotion processing in ASD (e.g. Capps et al., 1992; Losh & Capps, 2006;), and research finding atypical activation of the social brain network during tasks of social cognition (e.g. Castelli et al., 2002), it was predicted that adults with ASD would show impaired responses to social emotion scenarios. While atypical activation of the social brain network has also been found in basic emotion processing in adults with ASD (e.g. Ashwin et al., 2007), due to inconsistent behavioural research there were two predictions for the basic emotion scenarios. If there is no impairment in basic emotion processing in ASD, responses to basic emotion scenarios should be comparable with that of controls. Alternatively, if basic emotion processing is impaired in ASD, individuals with ASD should show impaired responses compared with controls.

8.3 Method

8.3.1 Participants

17 adults with ASD (15 male; mean age 36.11±3.78 years, range 18.02-61.06 years) and 16 IQ matched controls (NCs) (14 male; mean age 33.25±3.07 years, range 18.06-61.09) took part in this study. Participants were recruited through letters and emails that detailed the study and asked for their participation, and were paid £7.50 per hour for taking part. Participant consent was obtained before the study commenced and the study was approved by the local ethics committee.

Participants in the ASD group had all been diagnosed with ASD using established criteria (Autism Diagnostic Observational Schedule-G or ADOS; Lord et al., 2000). IQ was tested using the Wechsler Adult Intelligence Scale (Wechsler, 1997) for all individuals with ASD and two NCs. For the remaining 14 NCs, the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1997) was used to determine IQ. Verbal and non-verbal IQ data was not available for three participants in the ASD group, and for two participants in the NC group. No significant differences were found between the ASD and NC groups for age or IQ. Participant details can be found in Table 8.1.

Group	Mean Age (±SEM)	Mean Full-Scale IQ (±SEM)	Mean Verbal IQ (±SEM)	Mean Non-verbal IQ (±SEM)	Mean Full-Scale ADOS (±SEM)
ASD (*n*=17, 15 m)	36.11±3.78	111.59±4.48	114.5±5	108.36±5.41	11.65±0.84
NC (*n*=16, 14 m)	33.25±3.07	112.13±2.32	110.36±2.60	109.71±1.93	N/A
Group comparison	$t_{(31)}=.571$, $p>.05$ (NS)	$t_{(31)}=-.104$, $p>.05$ (NS)	$t_{(26)}=.735$, $p>.05$ (NS)	$t_{(26)}=-.236$, $p>.05$ (NS)	N/A

Table 8.1: Participant details for ASD and NC groups. Verbal and Non-verbal IQ were not available for three ASD participants and two NCs.

8.3.2 Design

See Chapter 7 for full description of task design. In brief, participants were presented with a pen and paper questionnaire with 32 emotional scenarios, of which 16 were designed to be evocative of social emotions (eight guilt; eight embarrassment) and 16 basic emotions (eight anger; eight fear). After each scenario, participants were asked to imagine how they would feel in that situation and rate how strongly they would feel each of the four emotions using a scale of 0 (not at all) to 10 (very strongly). Number of emotions was investigated to obtain a measure of mixed emotion. Mixed emotional responses were not discussed with participants, and neither was the distinction between social and basic emotion. Ratings of embarrassment and guilt for the social, and of fear and anger for the basic, emotional scenarios were also investigated as a measure of emotional intensity. The order of emotion words in the rating section for each scenario was randomised within and between participants and the order in which scenarios were presented was counterbalanced between participants. Participants were tested individually.

8.3.3 Analysis

To assess mixed emotion, scenarios were scored out of four (i.e. number of emotions rated as above 2cm) and a mean for the 16 social and 16 basic emotion scenarios was calculated for each participant. A mean social and basic mixed emotion score was then calculated for the ASD and NC groups. See Chapter 7 for full details of this procedure. To assess emotional intensity, average ratings for embarrassment and guilt in the social, and for fear and anger in the basic, emotion scenarios were calculated for each participant. A mean social and basic intensity rating was then calculated for ASD and NC groups. For both mixed emotion and intensity ratings, differences in social and basic responses between the ASD and NC group were investigated using ANOVA's with *Group* as a between-subjects factor (ASD vs. NC) and *Emotion Type* as a within-subjects factor (social vs. basic). Post-hoc simple effects were used to assess any differences found by the ANOVA. Full scale IQ was used as a covariate to control for effects of IQ on performance.

8.4 Results

8.4.1 Mixed emotion

Mean mixed emotion scores for social and basic scenarios in the ASD and NC groups are presented in Figure 8.1. ANOVA revealed no significant main effect of emotion type ($F_{(1,30)}=.280$, $p>.05$) or group ($F_{(1,30)}=2.210$, $p>.05$) and no significant interaction between group and emotion type ($F_{(1,30)}=.034$, $p>.05$).

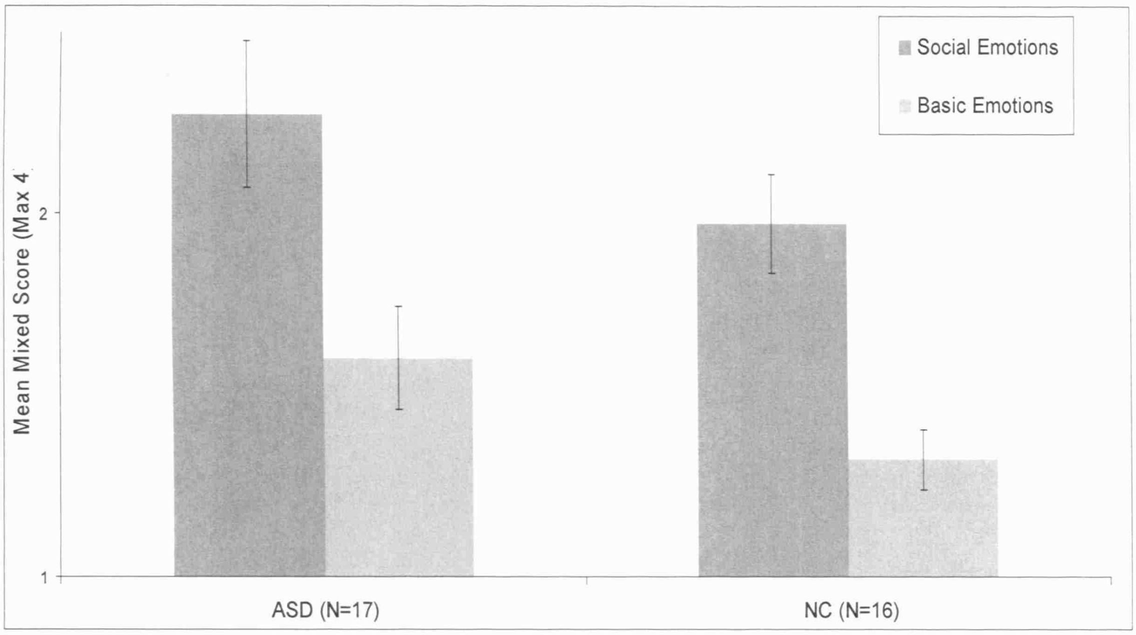

Figure 8.1: Mean mixed emotion rating for social and basic emotions for the ASD and NC groups. Both groups reported fewer mixed emotions for basic relative to social emotions.

8.4.2 Emotional Intensity

Mean intensity ratings for social and basic scenarios in the ASD and NC groups are presented in Figure 8.2. ANOVA revealed no significant main effect of emotion type ($F_{(1,30)}$=1.010, p>.05). There was no significant main effect of group ($F_{(1,30)}$=1.070, p>.05) and no significant interaction between group and emotion type ($F_{(1,30)}$=0.20, p>.05).

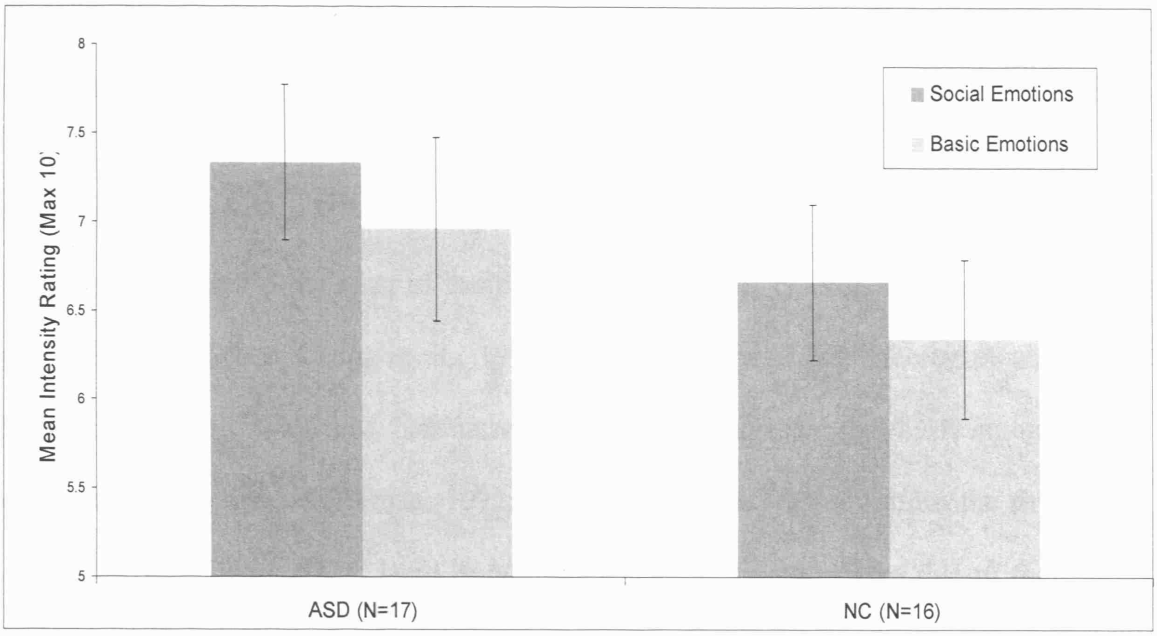

Figure 8.2: Mean emotional intensity ratings for social (embarrassment and guilt) and basic (fear and anger) emotion scenarios for the ASD and NC groups.

8.5 Discussion

This study investigated the mixed emotion reported for scenarios evocative of social (guilt and embarrassment) and basic (anger and fear) emotions in adults with ASD and healthy controls matched for age and IQ. It was hypothesised that individuals with ASD relative to controls would demonstrate impaired mixed social emotion understanding, due to impaired mentalising in ASD (Frith & Frith, 2003), and previous research finding impaired social emotion processing in ASD (e.g. Capps et al., 1992; Heerey et al., 2003; Losh & Capps, 2006). In contrast, there were two predictions for mixed basic emotion in ASD: impaired or unimpaired, due to inconsistent literature regarding this ability in ASD (e.g. Capps et al., 1992; Losh & Capps, 2006; Jaedicke et al., 1994; Rieffe et al., 2007). However, the results indicated comparable performance between ASD and controls for both social and basic mixed emotion. Investigation of emotional intensity for the social and basic emotions also indicated comparable performance between adults with ASD and healthy controls. These data suggest therefore that mixed social and basic emotion may be unimpaired in ASD, as measured by the current task.

8.5.1 Basic emotion in ASD

Finding unimpaired processing of basic emotion in ASD is consistent with a number of previous studies (e.g. Capps et al., 1992; Losh & Capps, 2006; Heerey et al., 2003; Baron-Cohen et al., 1997a;b). Normative research has suggested that basic emotions are universally recognisable (Ekman, 1972; 1999), and are expressed within the first three months of life (Izard, 1971; Izard & Malatesta, 1987). This could be due to their high evolutionary value as signs toward positive rewards (e.g. happiness) or danger (e.g. disgust). Basic emotions may therefore be to a degree instinctual and, as they do not necessarily rely on consideration of the social environment, their understanding may not be impaired in individuals with ASD.

The results contrast with a number of studies finding impaired basic emotion understanding in children with ASD (e.g. Jaedicke et al., 1994; Rieffe et al., 2007) and selective impairment of fear (Howard et al., 2000; Ashwin et al., 2007) and sadness (Boraston et al., 2006) recognition in adults with ASD. However, these discrepancies may be due to different task demands. For example, studies finding impaired fear (e.g. Ashwin et al., 2007) and sadness (e.g. Boraston et al., 2006) recognition could have been affected by the use of face perception paradigms and the inherent requirement to infer the mental states of others in these tasks (see Hill & Frith, 2003 for review). In contrast the current study involved reporting on subjective emotional responses relating to basic emotional scenarios which could have avoided such difficulties. Research that has utilised more similar research methods but have reported impaired basic emotion understanding in ASD (e.g. Jaedike et al., 1994; Rieffe et al., 2007) required the self-generation of verbal examples involving basic emotions. Research has indicated a specific difficulty in constructing emotional, but not non-emotional, experiences in ASD (Losh, 2005). The use of a non verbal response in the current task may have reduced task demands and led to the comparable performances found in this study.

While Rieffe et al. (2007) found comparable levels of emotional intensity in their 'single' emotion task, children with ASD relative to controls reported lower ratings of angry and sad in their 'mixed' emotion task. This may have been due to the lower mixed emotion reported for these emotions in the ASD group compared with controls (Rieffe et al., 2007). No differences in mixed emotion scores for the social or basic emotion scenarios in the current study could have led to the comparable levels of intensity ratings between individuals with ASD and controls. There are also a number of possible reasons for the discrepancy between current mixed emotion findings and data from Rieffe et al.'s (2007) study, where lower mixed emotion was reported in the ASD group relative to controls. First, while similar paradigms were used in both studies, Rieffe et al. (2007) used longer and more detailed stories (seven-sentences compared to two-sentences) than in the current study. In addition, when responding participants were given a choice of making either verbal or non-verbal responses and were required to interact with researchers to a greater level than in the current study. Reduced demands on story comprehension and social interaction may have led to more comparable performances on the current task. Second, Rieffe et al.'s (2007) study involved children with ASD, who may have had greater difficulties integrating information, attending to task stimuli, or imagining emotional responses, compared with adults with ASD. Third, the use of explicit instructions informing participants about the possibility of experiencing more than one emotion simultaneously in Rieffe et al.'s (2007) study could have had some effect on performance. The absence of information relating to mixed emotion in the current study controlled for this and may present a more implicit measure of this ability. Fourth, intelligence was not matched between children with ASD and TD controls. While the children with ASD were found to have average non-verbal intelligence (Rieffe et al., 2007), there may have been differences in ability between the two groups, which could have impacted on performance and resulted in the impaired mixed basic emotion reported by children with ASD relative to TD controls. In contrast, groups were matched for non-verbal, verbal, and full-scale intelligence in the current study, enabling greater control over such variables.

Dapretto et al. (2006) found that children with ASD showed an absence of activation in the inferior frontal gyrus (IFG) during the imitation of basic emotional expressions (fear, happiness, anger, sadness and neutral) from pictures of human faces. This was despite comparable behavioural performance as controls, and could reflect a failure to understand the internal significance of the observed and imitated emotions in ASD (Dapretto et al., 2006). Adults with ASD have also shown atypical activation during processing fearful facial expressions (e.g. Ashwin et al., 2007), which has been linked with atypical activation of the amygdala, consistent with studies of individuals who have amygdala damage (see Adolphs et al., 1995). While these studies involved recognition of emotion in other people rather than subjective emotional response, this data indicates the need for neuroimaging data alongside behavioural measures when investigating basic emotion processing in ASD.

8.5.2 Social emotion in ASD

Finding unimpaired social emotion understanding in ASD contrasts with previous research (e.g. Capps et al., 2002; Heerey et al., 2003; Losh & Capps, 2006) and is inconsistent with the marked social cognitive impairments characteristic of ASD (Frith & Frith, 2003). As with basic emotions, this discrepancy may be due to different task demands between studies, including the reduction of verbal requirements compared with studies investigating social emotions by Capps et al. (1992; 2006). In addition, rather than requiring detailed descriptions of personally experienced events as in Capps et al. (1992; 2006) or the use of facial expressions of social emotions (e.g. Heerey et al., 2003), the provision of hypothetical social scenarios could have resulted in finding unimpaired performance in ASD in the current study. For example, as a result of an impaired ability to mentalise, children with ASD are thought to lack the basic ability to experience relationship-based emotions (Hobson, 1993). Individuals with ASD also have difficulty encoding personal experiences for long term retention (Bowler et al., 2000). This is consistent with the specific deficit in personal episodic memory, i.e. the ability to encode and recall personally experienced events, found in ASD (e.g. Millward, 2000; Crane & Goddard, 2007). Therefore, individuals with ASD may not only be less likely to have the relevant experiences on which to generate adequate descriptions from memory, but in addition have a decreased capacity to do so, compared with TD children. This could have negatively impacted on performance in studies requiring verbal recall of socio-emotional events from memory in ASD (e.g. Capps et al., 1992).

Finally, the use of hypothetical scenarios evocative of embarrassment and guilt may have acted as a moderator of the social component in the current task compared with the use of photographs in studies finding impaired social emotion recognition (e.g. Heerey et al., 2003). The face is a powerful social stimulus (Horowitz, 1987), and it may be that the more indirect exposure to social situations in the current task led to comparable performance in ASD.

Therefore, performance by individuals with ASD on emotion tasks may be influenced by task demands, such as the requirement of a verbal response, memory, or emotion recognition. The exclusion of these requirements relative to previous research in this study could have led to comparable performance between ASD and controls on this task. However, this study is preliminary and further research is required.

8.6 Future directions

The ability of individuals with ASD to report subjective experiences relating to basic and social emotions, as assessed using the self-report measure in this study, may not be impaired in this clinical sample. Alternatively, a different paradigm may be required to detect any emotional impairment in ASD. The use of neuroimaging research to investigate the neural correlates associated with social and basic emotion understanding during performance on this task would provide additional data concerning the nature of emotion processing in ASD compared with controls. Atypical neural activation has been found during basic emotion processing in ASD (e.g. Ashwin et al., 2000), and has been found despite unimpaired behavioural performance (e.g. Dapretto et al., 2006). While these tasks employed face recognition paradigms, they emphasise the need for imaging technology alongside behavioural paradigms in investigations of emotion processing.

In addition, the provision of possible responses in this study could have enabled individuals with ASD to use cognitive strategies such as the selection of the 'most likely' response, thus masking underlying differences in emotion understanding in ASD. More ecologically valid tasks to investigate the way individuals with ASD respond emotionally in real-life social situations may also help clarify the nature of everyday emotion processing in ASD. For example, using disgusting odours (e.g. Zald et al., 1998) for basic emotions such as disgust, and dyadic interaction tasks (e.g. Coan & Allen, 2007 - see Chapter 7; Apperly at al., 2006 - see Chapter 3) for social emotions such as embarrassment.

8.7 Summary

Consistent with an impaired ability to mentalise in ASD (Frith & Frith, 2003), individuals with ASD have shown impaired processing of social emotions (e.g. Capps et al., 1992; Losh & Capps, 2006; Heerey et al., 2003). However, there has been inconsistent research regarding basic emotion processing in ASD (e.g. Jaedicke et al., 1994; Capps et al., 1992 cf. Rieffe et al., 2007). This study aimed to investigate social and basic emotion understanding in adults with ASD using a novel self-report questionnaire. The number of 'mixed' (Harris, 1989), or simultaneous, emotions felt in response to social (embarrassment, guilt) and basic (fear, anger) scenarios was compared between individuals with ASD and healthy controls. Intensity for the social and basic emotions in ASD and controls was also assessed. Due to well-documented difficulties with social cognition (see Frith & Frith, 2003) and impaired social emotion processing (e.g. Capps et al., 1992) in ASD, it was predicted that these individuals would demonstrate impaired mixed social emotion. In contrast, mixed basic emotion was predicted to be either unimpaired, or impaired, based on inconsistent past research (e.g. Capps et al. 1992 cf. Rieffe et al., 2007).

However, the results indicated comparable mixed emotion for individuals with ASD and controls for both basic (fear, anger) and social (embarrassment, guilt) emotion scenarios. This was consistent with studies finding unimpaired basic emotion processing in ASD (e.g. Capps et al., 1992; Losh & Capps, 2006) but contrasted with the same research finding impaired social emotion processing in ASD, and with studies finding impaired basic emotion understanding (e.g. Jaedicke et al., 1994; Rieffe et al., 2007).

These discrepancies could be due to the use of different task paradigms. For example, research has indicated that children with ASD have a specific difficulty in linguistically reconstructing emotional, but not non-emotional, memories in ASD (Losh, 2005). Previous research such as Capps et al. (1992; 2006) and Jaedicke et al. (1994) involved verbal descriptions of emotional memories, which may have affected performance in the ASD group. The use of stimuli with reduced verbal requirements in the current task may have decreased task demands, resulting in comparable performances between individuals with ASD and healthy controls. However, provision of emotional responses in the current study is not ideal and may have masked any underlying differences in emotion processing between groups. Further research is still required to clarify the nature of social and basic emotion understanding in ASD, with future studies employing imaging to assess neural correlates of mixed basic and social emotion processing in this clinical population.

The findings of all seven studies presented in the current thesis will be discussed in the next chapter.

Chapter 9

DISCUSSION

9.1 Investigating social cognitive change during adolescence

A wealth of research exists as to the nature of social cognitive development during childhood, and the neural correlates of social cognition in adults. Yet the period of adolescence has received relatively little attention from empirical research. This may be due to the fact that social cognitive abilities, such as mentalising, are apparent around the age of four years old in typically developing (TD) children (e.g. Wimmer & Perner, 1983; Perner & Wimmer, 1985). However, with the advance of sophisticated neuroimaging techniques, reports of protracted cortical maturation during adolescence have sparked interest in the impact of this development on cognition. Most studies have focused on the development of executive functions, and show continued change in these abilities consistent with maturation of the frontal cortex during this time (see Blakemore & Choudhury, review 2006).

Like executive function (EF), social cognitive abilities such as mentalising (Frith & Frith, 2003; Castelli et al, 2002), empathy (Farrow et al., 2001; Decety & Chaminade, 2003) and social emotion (Moll et al., 2002a;b), are associated with frontal regions such as the prefrontal cortex (PFC) in adults. Yet their development during adolescence has remained relatively unstudied. The empirical assessment of social cognitive change during adolescence was the aim of this thesis. It was hypothesised that social cognitive change would occur during adolescence, analogous to findings of executive function, and consistent with protracted maturation of frontal and temporal brain regions.

The majority of studies (e.g. Anderson et al., 2001; Luna et al., 2001; Tamm et al., 2002) investigating EF during adolescence have reported steady age-related linear improvement in performance, consistent with linear increases in total white matter (WM) volume during this time (e.g. Giedd et al., 1999; Sowell et al., 1999). However, a small number of studies have found non-linear development, where performance declines at puberty and this dip is then overcome by late adolescence (McGivern et al., 2002; Carey et al., 1980; Diamond et al., 1983). This inverted U shaped developmental trajectory is consistent with the non-linear pattern of grey matter (GM) density seen in the frontal and temporal lobes over the course of adolescence and into adulthood (Giedd et al., 1999; Toga et al., 2006). It was therefore predicted that social cognitive change may also occur during adolescence, and that the change may be in one of these patterns (linear or inverted U shaped).

9.2 Studies presented in this thesis

Studies were designed to investigate the impact of continued development of cortical regions including the PFC on social cognition during adolescence. Specifically, three aspects of social cognition were investigated: mentalising, empathy, and emotion processing. In addition, investigation of the nature of mentalising and emotion processing in autism spectrum disorder (ASD), which is characterised by impaired social cognition (see Frith & Frith, 2003 for review), was also investigated.

The experimental studies employed behavioural tasks pertaining to mentalising, empathy, and emotion processing. Investigation of change during adolescence assessed performance differences across three stages: pre-, mid-, and post-, puberty. Participants were classified into these three groups based on data collected from a physical development questionnaire (see Appendix A). Pubertal stage, rather than chronological age, was used due to evidence that pubertal hormones crucially affect brain development and behaviour (e.g. Romeo, 2003) and that maturation is only indirectly related to age (Wetzel, 1941; Krogman, 1950).

The first and second studies involved the development of a novel mentalising task based loosely on Happé's (1994) 'strange story' paradigm. Short vignettes with questions and multiple choice answers were presented on a laptop computer, with three experimental story conditions: mentalising, people non-mentalising, and physical. Inference of mental states was required only for the mentalising stories. For each story, the time taken to make a response following the presentation of a question and multiple choice answers was recorded, as well as the accuracy of response.

This mentalising task was first employed with adults with ASD and controls. While all participants demonstrated high levels of accuracy, significantly longer response times to selecting answers on mentalising stories relative to control stories was demonstrated by adults with ASD compared with matched control participants (Chapter 2). Impaired mentalising in ASD is consistent with previous research (e.g. Baron-Cohen et al., 1985; Happé, 1994) and suggested that this task may be a useful measure of the ability to mentalise. The task was therefore used to investigate the development of mentalising during adolescence, which may be affected by the continued development of key regions of the social brain such as the PFC. However, while an overall improvement in performance was found in all three conditions, no specific change in mentalising was found to occur across puberty (chapter 3).

An additional mentalising task, a questionnaire version of the 'reading the mind from the eyes' task (Baron-Cohen et al., 2001b) was employed in the third study to further investigate mentalising during adolescence (chapter 4). This task contained photographs of pairs of 'eyes' with four multiple choice answers regarding possible intentions being portrayed in each item. Having found impaired performance on this task in adults with ASD (Baron-Cohen et al., 1997a;b), the use of this task with an adolescent sample provided an additional measure of mentalising over the course of adolescence. Consistent with the first mentalising in adolescence study (Chapter 3) where no specific change in the ability to mentalise was found, no further development in mentalising was found over this time in the ability to infer intention from eye gaze.

Next, the development of empathy during adolescence was investigated (Chapter 5). Empathy is also associated with frontal regions of the brain such as the PFC (Farrow et al., 2001; Decety & Chaminade, 2003). An increase in empathy was therefore predicted due to the continued development of this region during adolescence (e.g. Giedd et al., 199; Paus et al., 1999). A pen and paper task was developed from Baron-Cohen et al. (2003) 'empathising-systemising' quotients, involving rating a series of sentences describing either empathising or systemising on a 4 point likert-type scale from strongly agree to strongly disagree. An example of an empathising sentence is: 'I enjoy caring for other people,' while an example of a systemising sentence is: 'In maths, I am interested in the rules and patterns of numbers'. Data obtained from this questionnaire indicated that empathising increased and systemising decreased during adolescence. This is consistent with social cognitive development that may have at least in part resulted from the protracted development of brain regions including the PFC, which are associated with empathy in adults (e.g. Farrow et al., 2001; Decety & Chaminade, 2003).

Basic emotion processing in adolescence was then investigated (Chapter 5). Basic emotions are universally recognised in facial expressions of others (Ekman, 1972; 1999) and the development of 'mixed' emotions, or an awareness of simultaneous emotions, occurs around age 10 to 12 (Harris, 1989; Larsen et al., 2007). Further progression in basic emotion processing past this age was predicted due to adolescence being a time of high emotional instability (Larson et al., 2002), and imaging research indicating protracted development of the frontal and temporal cortices associated with basic emotion processing in adults (e.g. Sprengelmeyer et al., 1998; Phillips et al. 1998b; Kesler-West et al., 2001). This was investigated using two computerised tasks.

The first task was an animations task (Boraston et al., 2006), based on a paradigm by Heider and Simmel (1944) where geometric shapes appear to move in life-like ways, such as chasing or tricking each other. For this study, the task was modified so that a triangle moved around a circle in a seemingly emotional way, evocative of one of four different basic emotions (anger, fear, happy, sad). The second basic emotion task was the Ekman task of facial affect (Ekman & Friesen, 1976), involving the presentation of 60 photos of people's faces expressing one of six different basic emotions (happy, sad, angry, scared, disgusted, surprised). The animations task presented emotional abstract stimuli requiring judgment about the intensity of portrayed emotion, while the Ekman task presented emotional face stimuli and required the selection of the correct emotion out of a possible six (multiple-choice). This enabled the investigation of change in basic emotion recognition over adolescence using two different types of non-verbal emotional stimuli. Despite cortical maturation, and consistent with research finding adult-levels of basic emotions by late childhood (Durand et al., 2007), the results from both tasks found no change in basic emotion processing during adolescence.

The sixth and seventh studies investigated the specific development of *social* emotions during adolescence (Chapter 7) and in individuals with ASD (Chapter 8). Social emotions such as embarrassment and guilt have an inherent mentalising component and are defined by social norms, and may be considered more complex than basic emotions such as fear and anger, which are universally recognised (Ekman, 1972; 1999) and do not involve the attribution of mental states to others. Research has found preferential activation of key regions of the social brain network, including the PFC and superior temporal sulcus (STS), to social compared with basic emotions (Moll et al., 2002a,b), and the difference in emotional complexity between these two types of emotion may be reflected in the later development of social relative to basic emotion understanding in childhood (e.g. Harris et al., 1987).

Complexity of social relative to basic emotion understanding during adolescence and in ASD was investigated using a novel self-report measure based on emotion stimuli from Moll et al. (2005). It measured the amount of 'mixed', or simultaneous, emotion (Harris, 1989) felt in response to social and basic emotion scenarios as an indicator of emotional complexity. Participants were presented with a series of two-sentence scenarios emotive of either basic (fear, anger) or social (guilt, embarrassment) emotions and asked to imagine how they would feel in each scenario. The number of emotions reported to be felt out of the four possible emotions in each scenario gave an overall indication of the amount of mixed emotion felt for social and basic emotions.

Data from the adolescent study (Chapter 7) indicated an increase in complexity or 'mixed' emotion (Harris, 1989) responding for social, but not basic, scenarios during this time. For adults with ASD and controls (Chapter 8), comparable performance for both social and basic emotions was found. Comparison of the mean mixed emotion scores showed similar levels in all three adolescent groups as found in the adult study for the basic emotion scenarios. However, for the social emotion scenarios, scores in the post-puberty group only were similar to those demonstrated in the adult study. Scores for the social emotion scenarios in the pre- and mid-puberty groups were lower than found in the adult study, which could emphasise the development of adult levels of social emotion over adolescence. Reasons for this seemingly differential impact of the social brain network on socio-emotional processing between adolescents and individuals with ASD is unclear, and is discussed in section 9.5.

In summary, all paradigms in these studies were intended to tap social cognitive abilities relating to mentalising, empathy, and emotion processing, based on well-replicated methodologies. The aim of this thesis was to investigate development of these social cognitive processes during adolescence, and compare performance on these tasks in adults with ASD relative to controls. First, social cognition in adolescence and in ASD is discussed in terms of data obtained in this thesis. Then, the contrasting results found for adolescents and individuals with ASD on the mentalising and emotion tasks developed for this thesis are considered. The limitations of this thesis are then presented, followed by overall implications and ideas for future research. Finally, conclusions are made as to the contribution made by this thesis to understanding social cognitive change in adolescence and the nature of its impairment in ASD.

9.3 Social cognition during adolescence

9.3.1 Mentalising in adolescence

The studies in this thesis did not find evidence that mentalising undergoes developmental change during adolescence. The progressive linear improvement found for all conditions on the mentalising task during adolescence (see Chapter 2) could reflect age-related improvement in executive functions, which were necessary for all conditions, as documented in a number of studies (Anderson, 2001; Luna et al., 2001; Tamm et al, 2002). For example, an increasing ability to attend to task material and to hold this information in mind may have resulted in improved performance across all conditions during adolescence. Development of improved motor coordination, attention, and/or older participants using more effective response strategies could have also resulted in more efficient response selection and decreased response times found in all conditions during adolescence on this task.

The overall female superiority on all three conditions of the mentalising task is consistent with research indicating a female bias for language skills (Maccoby & Jacklin, 1974; Kimura, 1999), which is apparent from childhood and remains stable into adulthood (Parsons et al., 2005). Females also outperform males in all major subjects through primary to high school, perhaps as a result of being more self-disciplined (Duckworth & Seligman, 2006). Other factors, such as greater levels of concentration or motivation in females relative to males, may have also contributed to performance differences found on this task.

The flat developmental trajectory found in the 'reading the mind from the eyes' task is consistent with the stability of performance in late childhood found on the computerised version of this task in a group of children eight to 12 year olds (Baron-Cohen et al., 2001b) and extends these findings up to age 17. However, further research is required to investigate the trend toward declining performance on this task between the ages of 10 to 17. The data may be compatible with the maturational trajectory of GM density of regions of the temporal cortex, such as the STS, which show gradual GM density increases that peak around age 16 years (Giedd et al., 1999) before declining into adulthood (Toga et al., 2006). Increasing levels of GM density over adolescence may have therefore adversely affected performance in older puberty groups. However, extraneous variables such as decreased motivation or attention in older participants could have also affected results and due to a number of limitations the data obtained from this study are preliminary (see Chapter 4).

Therefore, it may be that the ability to mentalise is completed during childhood. However, it is possible that change in the ability to mentalise during adolescence may have been too subtle to be detected using existing methodology. Development of more sensitive measures, perhaps using naturalistic methodologies such as that of Keysar et al. (2003) assessing mentalising during real-life interactions, in combination with neuroimaging technology would enable more sensitive investigations of mentalising during adolescence.

9.3.2 *Empathy in adolescence*

In contrast to mentalising, a preliminary study presented in Chapter 4 suggested linear increases in empathising (but not systemising) occurred during adolescence. This is consistent with protracted maturation of brain regions including the PFC, associated with empathy in adults (Farrow et al., 2001; Decety & Chaminade, 2003). In particular, the linear increase in empathy during this time is compatible with the progressive maturational event of myelination (Yakovlev & Lecours, 1967) and its associated linear increases in WM density in brain regions including the PFC during adolescence. This cortical maturation may lead to increased information processing (Blakemore & Choudhury, 2006) between childhood and late adolescence, and have a specific impact on empathic abilities. It may lead to the development of more complex and considerate care toward the subjective emotional experiences of other people. In addition, environmental factors such as increased societal pressure to conform to expectations of empathic responding toward others could also lead to increased empathising over the course of adolescence. In contrast to adults (Baron-Cohen et al., 2003), a significant negative correlation was found between empathising and systemising in adolescence. Future research is therefore required to investigate whether the correlation is developmental in nature, as well as to assess the relative impact of environmental factors on the development of empathy during adolescence.

9.3.3 *Emotion processing in adolescence*

Only a small number of studies to date have investigated emotional development past childhood. Stability of basic emotion processing found in this thesis (Chapters 6 & 7) is consistent with previous in late childhood (Durand et al., 2007; Ekman et al., 1980), and extends this up to age 16. Basic emotion processing might therefore be completed during childhood. This could be due to the relative cognitive simplicity or instinctive nature of basic emotions, as they are of high evolutionary value as signals of danger (e.g. fear) and reward (e.g. happiness). A maximal stage of development of basic emotions may therefore be reached prior to adolescence, resulting in the absence of change in basic emotion processing during adolescence, as found in this thesis.

In contrast to basic emotions, social emotions such as embarrassment and guilt depend on social norms and the ability to infer the thoughts of other people (mentalising). Imaging studies with adults have shown preferential activation of the PFC and STS during processing social relative to basic emotions (Moll et al., 2002a,b). The significantly higher levels of social relative to basic mixed emotion reported over adolescence (Chapter 7) indicates a change in emotional complexity specific to social emotion during this time. This extends previous research finding development of mixed basic emotion around the age of 10 to 12 years (e.g. Harris, 1989; Larsen et al., 2007) up to age 16 for social emotions. In addition, increased mixed social emotion during adolescence is consistent with the continued development during adolescence of the PFC and STS (Giedd et al, 1999; Sowell et al., 1999), associated with the processing of social emotion in adults (Moll, et al., 2002a;b). It may be that the heightened involvement of these key regions of the social brain, and their protracted development into adolescence, enabled more complex social emotional processing to occur during this period. In addition, environmental factors such as increased experience of emotional events and intensity of emotional relationships with others may have also impacted on socio-emotional development over the course of adolescence (Larson et al., 2002; Krettenauer & Eichler, 2006; Zeman et al., 2006 - see Chapter 7 for further description of these studies).

9.3.4 Dissociation between social cognitive processes in adolescence

Finding continued development of empathy and social emotion complexity in adolescence, yet no change in the ability to mentalise or in basic emotion processing, presents a dissociation between the development of aspects of social cognition and development of the social brain during this time. The reasons for this are unclear. One possibility is that the capacity for mentalising may be more limited compared with empathy or social emotion understanding. Research has found that even adults make mistakes when inferring the mental states of others (the 'curse of knowledge'; Camerer et al., 1989 – see Birch & Bloom, 2004 for a review). For example, adults demonstrate difficulties in inferring the mental states of others when involved in interactions in which they have prior knowledge, such as in Keysar et al.'s (2003) paradigm (see Chapter 3 for a description of this study). Mentalising in adulthood is therefore vulnerable to bias and inaccuracies, suggesting that this ability is difficult to master, regardless of level of maturity. A maximal level of expertise may therefore be reached during childhood, which is not affected by further social or cortical development during adolescence as found in this thesis. Similarly, basic emotion processing may reach its maximal level during childhood, although this is more likely to be due to the relative simplicity of this type of cognition rather than its complexity. For example, basic emotions such as fear and anger are often instinctive responses to danger or threat, and may be relatively complete early in life (e.g. Durand et al., 2007).

In contrast, the capacity for empathy and social emotion may not be as restricted, enabling continued development alongside the protracted maturation of cortical regions including the PFC and STS during adolescence. Unlike mentalising, which involves making subtle inferences about the thoughts and feelings of other people who are notoriously unpredictable, situations evoking empathy and social emotions are associated more with a *subjective* response toward others. In addition, a greater capacity for development of subjective responses may be due to the greater predictability of experiences evoking empathy or social emotional responses. For example, these situations are often more dramatic and may be more predictable (e.g. seeing a person crying is likely to evoke empathy; falling over and people laughing at you is likely to evoke embarrassment) than inferring what another person might be thinking, which may be affected by a range of different and unknown factors (e.g. personality, past events, future goals). Therefore, while increasingly complex social experiences during adolescence may not cause any development in the ability to infer mental states, the understanding of empathy and social emotions may be increased. The protracted development of regions such as the PFC and STS during adolescence may play a role in enabling this development to occur. The various contributions of environment and neural development in this dissociation would be an interesting avenue for future research.

A second possibility is that the differences in development between these aspects of social cognition result from differential recruitment of the social brain network. While research has demonstrated the involvement of regions of the PFC in all aspects of social cognition investigated in this thesis, this brain area is not a homogeneous structure (Pandya & Yeterian, 1995). In addition to connections with the parietal and temporal lobes, as indicated by neuroimaging research employing social cognitive tasks (e.g. Flecther et al., 1995 - see section 1.2 of Introduction for description of these studies), the PFC has connections with many other regions of the cerebral cortex including limbic structures such as the amygdala and hippocampus (Robbins, 1996). Functional differences are likely to exist within these anatomical connections for different aspects of social cognition, as has been found for executive function (see Robbins, 1996). Cortical networks associated with processing empathy, and social emotion processing, may therefore be affected by maturational events occurring in this region during adolescence while mentalising and basic emotion processing remain unchanged.

9.4 Mentalising and emotion processing in Autism

There has been inconsistent evidence regarding the nature and existence of impaired mentalising in ASD. A number of studies have found impaired mentalising (e.g. Baron-Cohen et al., 1985; Happé, 1994) others have not (e.g. Sullivan et al., 1994; Tager-Flusberg & Sullivan, 1994). Data obtained in this thesis (Chapter 2) is consistent with impaired mentalising in ASD, lending support to the mentalising deficit account of ASD when verbal demands are minimised by using a computerised task in which response time, rather than accuracy, is used as the dependent variable. Decreased activation of the medial PFC, STS and temporal poles has been found in adults with ASD during tasks involving mentalising (e.g. Castelli et al., 2002; Happé et al., 1996). Such atypical activation of the social brain may reflect weaker cortical engagement of the mentalising network during situations requiring mental state attribution in ASD compared with controls (Bird et al., 2006). In addition, individuals with ASD show poor attention to eye gaze (e.g. Baron-Cohen et al., 1997a;b; 2001a) indicating an absence of attending to the thoughts and intentions of other people. Research has also found activation of adjacent regions of the medial PFC in ASD during tasks of mentalising vs. non-mentalising (Happé et al., 1996), suggesting that individuals with ASD might have developed different cognitive routes to processing stimuli requiring mentalising (Happé & Frith, 1996). Functional and strategic differences could have manifested as longer response times to situations requiring mentalising in ASD, as found in this thesis.

In contrast to impaired mentalising, comparable performance between individuals with ASD and controls were found for social and basic emotions (Chapter 8). In addition, greater levels of mixed emotion were reported for social relative to basic emotions by both groups, reflecting an appreciation of the greater complexity of social relative to basic emotions in ASD. Unimpaired processing of basic emotions in ASD is consistent with studies by Capps et al. (1992; 2006), where individuals with ASD provided as detailed accounts of situations in which they had experienced basic emotions (e.g. anger) as control participants, but inconsistent with a number of studies finding impaired basic emotion understanding (e.g. Jaedicke et al., 1994; Rieffe et al., 2007). In addition, finding a comparable level of mixed social emotion in ASD relative to controls is inconsistent with Capps et al. (1992; 2006) finding impaired social emotion processing in ASD.

Research has found that individuals with ASD are able to use self-report measures effectively when reporting on aspects of subjective emotional experience (i.e. alexithymia and depression; Hill et al., 2004; Berthoz & Hill, 2005), suggesting that the emotion questionnaire used in this thesis may be a useful methodological tool for investigating mixed emotion understanding in ASD. The effective use of the questionnaire by individuals with ASD may also be reflected by the reporting of greater levels of mixed emotion for social relative to basic emotions, consistent with the greater complexity of social relative to basic emotions, and with control adults and data from the adolescent study. In addition, research has found a specific difficulty in linguistically reconstructing emotional (but not non-emotional) memories (Losh, 2005), and a deficiency in personal episodic memory (e.g. Millward, 2000; Crane & Goddard, 2007), in ASD. Individuals with ASD may therefore be unimpaired at reporting personal experiences relating to social and basic emotions using self-report questionnaires with reduced linguistic demands, as found in this thesis, but impaired at using other tasks such as the verbal recall of events involving social (e.g. Capps et al., 1992; 2006) or basic (e.g. Jaedicke et al., 1994; Rieffe et al., 2007) emotional events.

9.4.1 Dissociation between mentalising and emotion in ASD

A dissociation between mentalising and emotion processing, with impaired mentalising and unimpaired emotion processing relative to controls, was found in ASD. This suggests that these individuals may have difficulty with understanding mental states but experience similar emotional responses as healthy people. Anecdotal evidence has indicated that individuals with ASD often want to form meaningful relationships with other people but that this is rarely obtained (Ceseroni & Garber, 1991). The desire to establish meaningful relationships with others could reflect unimpaired emotion processing, while the difficulties in doing so could be the result of impaired mentalising, in ASD as found in this thesis. It has been suggested that social competence depends on both mentalising and emotion (Astington, 1996; Davies & Stone, 2003). It may be that difficulties specific to mentalising, and not emotion processing, as reported in this thesis are sufficient therefore to result in the impoverished social cognition so characteristic of ASD.

9.4.1.1 Comparison between ASD and Psychopathy

The opposite dissociation, i.e. unimpaired mentalising and impaired emotion processing, has been found in individuals with psychopathy (Blair et al., 1996). Psychopathy is a developmental disorder characterised in part by callousness, a diminished responsibility for remorse, and poor behavioural control (Hare, 1991). Blair (1995) linked psychopathy to early dysfunction of the amygdala and its consequent impairment in processing fearful and sad expressions of emotion, causing failure to learn to avoid behaving in a way that causes harm to other people (see Blair, 2003 for a review). Socialisation is therefore markedly impaired in this disorder. Atypical amygdala function (see Baron-Cohen et al., 2000 for review), and a deficiency in fear and sadness recognition (Ashwin et al., 2000; Howard et al., 2000; Boraston et al., 2006), has also been found in ASD. However, rather than manifesting as impaired emotion processing as in psychopathy, this dysfunction may negatively impact on the ability to mentalise in ASD (although the contribution of amygdala dysfunction in ASD is less well defined than in psychopathy; see Blair, 2006 for a review). The impoverished socialisation demonstrated in both disorders is likely therefore be the result of different underlying social cognitive impairment. While individuals with ASD may be unimpaired at processing subjective emotion, they may have difficulty socialising with other people due to their impoverished ability to understand their thoughts and feelings (mentalise). In contrast, individuals with psychopathy have an impaired ability to experience and recognise negative emotions such as fear and guilt, and this has been proposed to lead to the impaired socialisation demonstrated by these individuals (Blair, 1995).

9.4.2 Methodological differences between novel tasks and previous research

Due to the wide range of methodology used in previous studies, and the development of novel tasks in this thesis, discussion of the differences between these paradigms is necessary. The provision of non-verbal responses in both mentalising and emotion tasks developed in this thesis compared with the self-generation of verbal responses used by previous research investigating mentalising (e.g. Happé, 1994) and emotion processing (e.g. Capps et al., 1992; Rieffe et al., 2007), may be analogous to tasks of recall and recognition in memory. The novel tasks could have enabled responses to made on the basis of what is 'most likely' to be correct or appropriate, rather than the independent generation of responses. In addition, differences in cognitive strategy or neural activity in ASD relative to controls may have been detected in the response time measurement of the mentalising task, and manifested as longer response times in the mentalising condition in ASD (see section 9.4). Previous research investigating mentalising in ASD may not have found impairment in this dependent variable due to allowing relatively lengthy time to respond, for example up to 40 seconds as in the Happé et al. (1996) study. The use of shorter response times (around 6.5 seconds) in the study reported in this thesis appears to have presented a more sensitive measure of ability to mentalise in ASD.

The lack of comparable response time measure in the emotion task could have masked such subtle differences in time taken to respond to emotional scenarios. Emotion research by Piggot et al. (2002) has indicated longer response times but comparable accuracy in ASD relative to controls while matching labels to facial expressions of basic emotion. It is possible that similar deficits may be seen in ASD during the evaluation of subjective emotional experiences, as investigated in this thesis. Atypical social cognitive function in ASD may have a specific detriment on response time, as found in the mentalising task. The addition of a response time measure in the emotion task would therefore enable further investigation of this possibility and would be a useful addition to future research.

9.5 Double dissociation between social cognitive processes in individuals with ASD and typically developing adolescents

In contrast to the impaired mentalising but unimpaired emotion processing found in individuals with ASD, adolescents demonstrated unimpaired mentalising but increased complexity of social emotion processing, using the same tasks developed in this thesis. These results suggest that the development of the social brain during adolescence may have a differential effect on social cognitive abilities, and that the atypical functioning of the social brain network may have the reverse effect on social cognitive abilities in ASD. Speculatively, this could be due to a number of different factors. First, ASD is a clinical disorder characterised by impaired social cognition, in which decreased or even absent activation of key areas of the social brain has been found during tasks of social cognition (e.g. Castelli et al., 2002; Happé et al., 1996). In contrast, the adolescents were typically developing and expected to show only subtle differences in social cognitive function as a result of continued cortical development. Atypical, versus immature, function within the social brain network could have differentially affected mentalising and emotion processing in ASD and adolescence respectively, leading to the current findings. Second, as discussed in section 9.3.5 with adolescents, mentalising may be qualitatively different to empathy and social emotion understanding. While all of these processes involve other people, mentalising involves understanding the mental states whereas empathy and socio-emotional processing involves making subjective emotional responses. This may have differentially affected performance in individuals with ASD (see section 9.4.1) and adolescence (see section 9.3.5). However, further research is required to investigate these possibilities.

The limitations of this thesis will now be discussed.

9.6 Limitations

There are a number of limitations to the studies in this thesis. First, there are limitations imposed by the exclusive use of behavioural methodology. Inclusion of neuroimaging in collaboration with the behavioural measures developed in the current thesis would have extended findings and helped uncover neural substrates of the various concepts investigated.

Second, the use of single-sex participant groups in a number of studies with adolescents may restrict applicability of findings. While beyond the scope of this thesis, research indicates sex-specific differences in the timing and rate of pubertal development (Herman-Giddens et al, 1997; Grumbach & Styne, 1998) and in brain development (e.g. Goldstein et al., 2001). In addition, gender differences in mentalising (e.g. Charman et al., 2002), empathy (Jolliffe & Farrington, 2006) and emotion (e.g. Pine et al., 2004) consistent with these changes have been found. Despite research suggesting that the developmental trajectories of GM and WM volume do not differ significantly between males and females during development (Giedd et al., 1999), investigation of gender differences in social cognitive development is important for future research in this field.

Third, while the use of self-report development questionnaires is a more reliable gauge of pubertal status than chronological age alone, clinical measures (e.g. Tanner stages; Tanner, 1962) may have provided more reliable classification into puberty groups. Where possible, this would be desirable for future research. Fourth, a number of investigations would have benefited from larger participant groups. This would have improved statistical power and reliability of results. Finally, the use of more ecologically valid paradigms such as real-life social interactions similar to those used by Keysar et al. (2003) or Apperly et al. (2006) (see Chapter 2 for description of these paradigms) may have increased the validity of data obtained during investigations of social cognitive change during adolescence.

9.7 Implications and future directions

Data obtained from the studies in this thesis provide avenues for extending research in investigating the development of social cognition during adolescence. Evidence of increasingly mixed social emotion processing and empathy during adolescence indicates change consistent with protracted development of the frontal and temporal regions of the brain during this period. The use of more ecologically valid paradigms, such as the use of humanoid avatars as a means of creating more life-like stimuli (e.g. Garau et al., 2001), dynamic rather than static face stimuli (e.g. Rosenblum et al., 2002), and real-life interactions requiring mentalising such as those used with adults by Apperly et al. (2007), would allow further assessment of social cognitive abilities in ASD during real world interactions. The impact of social cognitive impairment in ASD on relationships and every day function could be more realistically demonstrated through the use of such methodology alongside more controlled experimental techniques, as used in this thesis.

Factors other than neural development may have also impacted on social cognitive development during adolescence. This period of life is a time of vast social change, involving shifts in relationships between peers and family (e.g. Zeman & Garber, 1996; Bieseker, 2001) and increased understanding of the inter-personal consequences of behaviour (Zeman et al, 2006). Research investigating the influence of this environmental change, which may impact most heavily on empathy and social emotion complexity, is required. In addition, genetics may play a role in determining social cognitive response over development. For example, Caspi et al. (2002) found that in a sample of maltreated children only those possessing a certain predisposing gene went on to exhibit severely antisocial behaviour.

This emphasises a need for interdisciplinary research to explore the possible contributions of a wide range of factors on social cognition during adolescence. Investigation of the impact of empathic and social emotional change during adolescence on areas such as education, social policy, and healthcare would enable better understanding of this important life period. The incidence of antisocial behaviour increases 10 fold in adolescence (Moffitt, 1993) and behavioural and emotional problems during this period have considerable personal and societal cost (Wolfe & Mash, 2006). These difficulties could in part be due to the immaturity of frontal and temporal regions of the brain in adolescence, associated with the modulation and control of emotional and empathic understanding. Greater appreciation of the relative immaturity of these social cognitive processes during adolescence by society may encourage more positive relationships between young people and adults. Already, issues relating to diminished responsibility due to developmental immaturity during adolescence are controversial issues within the field of criminal justice (see Steinberg & Scott, 2003). Further research is required to add weight to the idea that adolescence may be an important time for social cognitive development.

Educational interventions, such as the use of tools for training in emotion or empathic responding with other people, could assist in developing social competence and managing problem behaviour in adolescence without resorting to government policies such as the use of antisocial behaviour orders (ASBOs). For example, the use of cognitive behaviour therapy may help increase understanding of own and other's emotions, perhaps enabling more successful social relationships for some adolescents. The popularity of interactive computer games and robotic 'pets' see (see http://www.neatstuff .net/robopets.html) could be capitalised upon as a method of providing ways of educating young people that has been unavailable previously. Social interactions using avatars in virtual reality environments (e.g. 'second life' in which an individual can become fully immersed in a virtual world; see http://secondlife.com/), or robots in real-life settings, could be used in this way to explore and practice successful interpersonal communication and understanding during adolescence. The use of similar methods has been used to aid emotional understanding of other people in children with ASD, with some success (see Fabri & Moore, 2005).

The tasks developed in this thesis may provide useful methodological tools for further investigations. For example, the novel mentalising task (Chapter 2) might be useful for use with clinical groups. While further research is required to investigate the reasons for the mentalising impairment in ASD found by this task, it has a number of advantages over previous methodologies. First, it is relatively quick, taking no longer than 30 minutes for each participant. Second, the computerised nature of the task enables measurement of response times as well as error rate. Third, the use of multiple choice answers is less open ended than asking participants to make a verbal response as in past research (e.g. Happé, 1994), enabling a more efficient and perhaps more accurate scoring procedure. Fourth, the inclusion of two control tasks controls for a variety of factors such as the presence of people and general cognitive demands, which might influence the results. Similarly, the novel mixed emotion questionnaire may offer an emotion task that has reduced linguistic demands compared to previous methodologies, and could be of use for both developmental and clinical research.

Finally, due to the paucity of research methodology available for investigating social cognition during adolescence, the version of Baron-Cohen and colleague's (2003) EQ/SQ questionnaire and the mixed emotion questionnaire developed in this thesis for use with adolescents (Chapters 5 and 7) and individuals with ASD (Chapter 8) could be employed in future studies. In particular, these tasks could be used to investigate gender differences during adolescence, which is important for future investigations of normal social cognitive development.

Conclusions

Some change in social cognitive development was found during adolescence. The propensity toward empathic responding, and the understanding of social mixed emotions, both increased over this time. This was consistent with predictions, based on the protracted development of brain regions associated with social cognition, in particular the PFC, during adolescence. However, the ability to infer the mental states of others (mentalising) showed no further development during adolescence. In addition, there was no change in basic emotion processing during this time. These processes may have reached a maximal level during childhood, which is not achieved until later in development for empathy and social emotion processing.

In contrast to the adolescent studies, individuals with ASD demonstrated impaired mentalising but unimpaired emotion processing. This suggests that individuals with ASD may have difficulties with inferring the mental states of other people, but may be relatively unimpaired at reporting subjective experiences relating to basic and social emotions. This is opposite to the dissociation demonstrated by individuals with psychopathy, also a developmental disorder characterised by impaired socialisation (Blair, 1996). In addition, the double dissociation for mentalising and emotion processing between individuals with ASD and adolescents found using the same tasks developed in this thesis is of interest. It suggests that the social brain may have a differential effect on aspects of social cognition during typical development across adolescence relative to individuals with ASD.

Overall, it is hoped that studies in this thesis increase interest and knowledge about social cognition during adolescence, and provide additional data toward understanding the nature of mentalising and emotion processing in ASD.

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Websites

Autism Research Centre: http://www.autismresearchcentre.com

Robotic games: http://www.neatstuff.net/robopets.html

Virtual reality site: http://secondlife.com/

Appendices

APPENDIX A: Development Questionnaire developed from Carskadon & Acebo (1993) (Chapters 3-7).

APPENDIX B: Examples of stimuli from the computerised mentalising task (Chapters 2&3).

APPENDIX C: Examples of stimuli from the emotion questionnaire (Chapters 7 & 8).

Appendix A

Date ____________

Subject number ____________

Development Questionnaire (Female)

This is a standard questionnaire that is widely used to look at development during childhood and adolescence.

This questionnaire may be completed by:

*The parent(s)

*The parent(s) and pupil

*The pupil

*Please place a tick against the option chosen.

The questions are about physical changes that normally happen to young people at different ages. As we are researching development during childhood and adolescence, it is important for us to know at approximately what stage each child/young person is in terms of physical development. We would therefore like to ask you to do your best to answer these questions carefully.

If you do not understand a question or do not know the answer, try to answer as best as you can or leave it blank. If you don't feel comfortable answering a question, please just leave it blank and move on to the next one.

If you have any queries about this questionnaire, please contact us.

Dr. Sarah-Jayne Blakemore   Ms Stephanie Thompson

Questionnaires available on request

Please answer by filling in the blanks or circling the letter in front of the most appropriate answer (only choose one answer).

1. What is your date of birth?

____

2. How tall are you?

________ feet and _________ inches tall OR

________ metres and ________ centimetres tall.

3. How would you describe any recent growth in height?

a. Not yet had a growth spurt (a "spurt" means a sudden increase in height)
b. A growth spurt seems to have just begun
c. Noticed a definite growth spurt taking place
d. Finished having a growth spurt and have barely grown at all recently

4. How much have you grown in height in the last 6 months?

Grown by ______________ centimetres / inches.

5. How much do you weigh?

________ stone and _________ pounds OR

________ kilograms.

6. Have you started having periods yet?

a. Yes
b. No

If 'yes', at what age did they start?

_________ years and ________ months old.

Questionnaires available on request.

7. Would you say that your bodily hair (e.g. under your arms):

a. Has not yet started growing
b. Has only just begun to grow
c. Has been increasing for some time
d. Is no longer increasing – it seems to have stopped growing

8. Have you noticed any skin changes on your face or neck, especially spots?

a. I have not noticed any changes
b. I have begun to notice small changes
c. I am definitely noticing a lot of changes at the moment
d. The changes seemed to have finished happening

9. Do you think any changes in your physical development have been happening any earlier or later than most other girls your age?

a. much earlier
b. a little earlier
c. at about the same time
d. a little later
e. much later

10. Are you left or right handed?

a. Left
b. Right

Thank you very much for answering this questionnaire! ☺

Note: The male developmental questionnaire contained the same instruction page and questions 1-5 as the female developmental questionnaire shown above.

Questions 6-11 of the male questionnaire are presented overleaf.

6. Have you begun to grow hair on your face?

a. It has not yet started growing
b. It has only just begun to grow
c. It has been increasing for some time
d. It is no longer increasing - it seems to have stopped growing

7. Would you say that other bodily hair (e.g. under your arms):

a. Has not yet started growing
h. Has only just begun to grow
c. Has been increasing for some time
d. Is no longer increasing - it seems to have stopped growing

8. Have you noticed any skin changes on your face or neck, especially spots?

a. I have not noticed any changes
b. I have begun to notice small changes
c. I am definitely noticing a lot of changes at the moment
d. The changes seemed to have finished happening

9. Have you noticed a deepening of your voice?

a. It has not yet started changing
b. It has only just begun to change
c. It is definitely changing a lot at the moment
d. It has deepened and is not changing anymore

10. Do you think any changes in your physical development have been happening any earlier or later than most other boys of your age?

a. much earlier
b. a little earlier
c. at about the same time
d. a little later
e. much later

11. Are you left or right handed?
a. Left
b. Right

Thank you very much for answering this questionnaire! ☺

Appendix B

MENTALISING

1. Paul is going in to town to meet his friend Jim at the funfair. Paul hates fast rides but Jim loves them. When Jim asks him to come on a fast ride with him, Paul shouts 'Yes I love fast rides!!'

Why does Paul say this?

Because Paul doesn't realise it's fast	Because Paul doesn't want to show he's scared	Because Paul thinks that it might be fun

2. Gary knows he is a good singer, but hates singing in front of strangers. When his mum says that she has entered him into a singing contest, he tells her that he cannot go as he is 'rubbish'.

Why does Gary say that he is 'rubbish'?

Because he knows he cannot sing	Because he feels really unwell	Because he is scared of singing in public

3. John hates the colour orange, but loves the colour blue. His mum buys him a blue scarf and his auntie buys him an orange hat. When they ask him whether he liked the presents, John says that he's really happy with both of them.

Why does John say that he's really happy with both of them?

Because he wants a new scarf and hat	Because he doesn't want to hurt his auntie's feelings	Because he loves presents

Entire task available on request

PEOPLE NON-MENTALISING (CONTROL 1)

1. Bob is very tall and Jim is very small. One day at the funfair, they see the rollercoaster, and read the sign saying that 'for safety reasons riders must be above five feet tall'. Only Bob rides the rollercoaster.

Why does only Bob ride the rollercoaster?

Because Jim has to go home	Because Jim is too small for the rollercoaster	Because Jim does not have enough money

2. Sam is walking through the rain when a gust of wind blows his umbrella out of his hand. It lands amongst the thorns of a large bush, and Sam pulls it free. As he walks home, he feels his head getting wet.

Why does Sam's head get wet?

Because the umbrella blew away	Because the umbrella has holes in it	Because the wind is blowing the rain onto him

3. John and Ben are neighbouring potato farmers. They have the same amount of land to grow potatoes on, and use the same equipment for collecting the potatoes. John uses fertiliser on his soil while Ben does not. John grows more potatoes than Ben.

Why does John grow more potatoes than Ben?

Because Ben is very bad at growing potatoes	Because John steals potatoes from Ben	Because fertiliser helps potatoes grow

 Entire task available on request

PHYSICAL (CONTROL 2)

1. There is a large mountain range surrounded by a river. The mountains are very rocky. On one of the mountains, a large boulder falls from a rock-face. A little while later, there are ripples in the river.

Why are there ripples in the river?

Because the boulder fell into the river	Because there are fish in the river	Because it is very windy

2. There is a forest and it is full of very tall trees. The trees are really close together, with no spaces in between them, and their branches are full of large green leaves.
There are no plants growing on the forest floor.

Why aren't there any plants growing on the forest floor?

Because the forest floor is too stony	Because the trees block the sunlight	Because the soil is bad for the plants

3. It has been raining all day. The drains are blocked and water gushes down the streets. At the end of the town, there is a small river. After a while, the water levels of the river begin to rise.

Why does the water level begin to rise?

Because it is high tide	Because the water runs in from the streets	Because the river is blocked

Appendix C

Examples of emotion scenarios from the mixed emotion questionnaire

BASIC EMOTION: FEAR

1. *'Your friend was being bullied at school. The bully threatened to hurt you too'*

2. *'You felt something on your neck. It was a huge spider crawling on you'*

3. *'It was a very dark and windy night. Suddenly all the lights went out in the house'*

BASIC EMOTION: ANGER

1. *'At school you tried really hard on a test. Your teacher thought you had cheated'*

2. *'You got a new walkman for your birthday. You lent it to your brother and he broke it'*

3. *'You saw your brother in your room. He took something without asking'*

SOCIAL EMOTION: EMBARRASSMENT

1. *'You dressed as a clown for a fancy dress party. When you got there, no one else was dressed up'*

2. *'You were eating lunch with your friends. You didn't realise you had food stuck in your teeth'*

3. *'You made a nasty joke about your best friend. You didn't realise that she was standing behind you'*

SOCIAL EMOTION: GUILT

1. *'You asked your mum to buy you a hamster. You did not look after it properly and it died'*

2. *'Your little sister asked you to help tie her shoe laces, but you didn't. She tripped, fell and hurt herself'*

3. *'You told your friend you would meet her after school. You forgot, and she was waiting for ages in the playground by herself'*